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THE COST OF CLEAN WATER. VOLUME III. PAPER MILLS, EXCEPT BUILDING

Federal Water Pollution Control Administration
Washington, D. C.

November 1967

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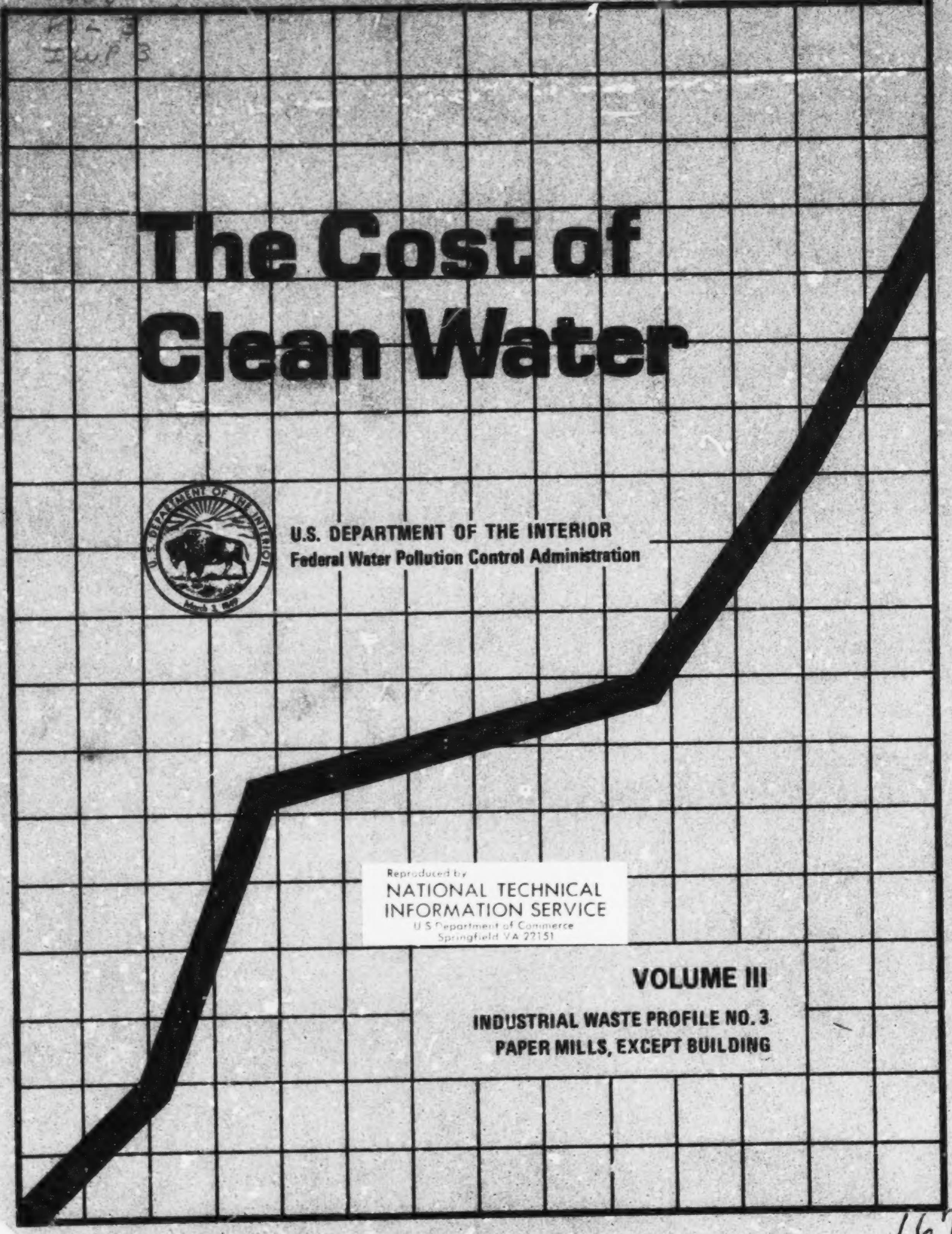

The Cost of Clean Water

U.S. DEPARTMENT OF THE INTERIOR
Federal Water Pollution Control Administration

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VOLUME III

INDUSTRIAL WASTE PROFILE NO. 3
PAPER MILLS, EXCEPT BUILDING

167

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THE COST OF
CLEAN WATER

Volume III

Industrial Waste Profiles
No. 3 - Paper Mills

U. S. Department of the Interior
Federal Water Pollution Control Administration

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I

PREFACE

The Industrial Waste Profiles are part of the National Requirements and Cost Estimate Study required by the Federal Water Pollution Control Act as amended. The Act requires a comprehensive analysis of the requirement and costs of treating municipal and industrial wastes and other effluents to attain prescribed water quality standards.

The Industrial Waste Profiles were established to describe the source and quantity of pollutants produced by each of the ten industries studied. The profiles were designed to provide industry and government with information on the costs and alternatives involved in dealing effectively with the industrial water pollution problem. They include descriptions of the costs and effectiveness of alternative methods of reducing liquid wastes by changing processing methods, by intensifying use of various treatment methods, and by increasing utilization of wastes in by-products or water reuse in processing. They also describe past and projected changes in processing and treatment methods.

The information provided by the profiles cannot possibly reflect the cost or wasteload situation for a given plant. However, it is hoped that the profiles, by providing a generalized framework for analyzing individual plant situations, will stimulate industry's efforts to find more efficient ways to reduce wastes than are generally practiced today.

James M. Quigley
Commissioner
Federal Water Pollution Control Administration

PAPER MILLS
INDUSTRY WASTEWATER PROFILE

Prepared for F.W.P.C.A.

F.W.P.C.A. Contract 14-12-10
June 30, 1967

Federal Water Pollution Control Administration
November 1967

III

SCOPE OF MATERIAL COVERED

The industrial wastewater profile covers the Paper Industry and integrated pulp and paper mills in the United States as defined by Standard Industrial Classification 2621 (except buildings) of the U. S. Department of Commerce. The principal areas of discussion are: the fundamental manufacturing processes and significant water and gaseous wastes generated by each operation, process water use and re-use, waste quantities and characteristics, waste reduction practices (including both waste treatment and in-plant processing) and their effectiveness, and waste treatment costs. Projections or estimates have been made for the changes, developments, and operating practices that will be prevalent in 1977 for each area of discussion.

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SUMMARY

Fundamental Processes, Subprocesses, and Resulting Wastewaters

Integrated pulp and paper mills are discussed as a unit operation rather than as separate operations, since wastewater treatment is dependent upon total in-plant wastewater abatement measures and total wastewater quantities and characteristics. The pulp mill includes the fundamental processes of wood preparation, pulping, screening, washing, thickening, and bleaching, whereas the fundamental processes in the paper mill include stock preparation, paper machine operation, converting, and finishing.

Wood preparation begins with the movement of the log from the stock pile to the debarking facilities. This is generally accomplished by moving the log by a crane to a conveyor or a log flume. The log is soaked prior to moving through the flume (where great quantities of wastewater are generated), and the wastewater is reused if the grit and bark are removed. At the debarking facilities, the bark can be removed from the log by several methods; mechanical, chemical (not applied), and long log (newer technology). Bark that has been removed increases solid wastes disposal problems, and to date, incineration for heat recovery, composting, and by-product recovery have found the greatest number of applications. The debarked log is sent to the chipping facilities where it is fragmented into chips, suitably sized to enhance the penetration of cooking liquor (in the digesting operation) into the wood. Wastes from wood preparation consist of bark, soluble saps dissolved from the wood washing process, and grit.

Mechanical chipping is the most widely practiced method, but another method has been developed, which has not yet found wide acceptance, is a two-step process, where the log is first compressed perpendicular to the fiber and then cut across the fiber. The chips resulting from all methods have to be cleaned and separated to insure that only chips of uniform size will be supplied to the digester.

Pulping, the process wherein wood and other fibrous plants are converted into fibers adaptable for use in paper making, is currently accomplished by four different processes; mechanical, chemigroundwood, sulfate, and sulfite.

Mechanical pulp (groundwood), is manufactured using a grinder. Small blocks of the log are forced against a grindstone in the presence of water. Newsprint, low-grade sanitary tissue and paperboard can be made from this type of pulp. Although significant quantities of wastewater are generated in cooling, cleaning, and lubricating the grindstone and in carrying the pulp, modern technology has introduced water reuse in the process which has greatly reduced the amount of wastewater discharged to the sewer. Wastewaters that are discharged to the sewer contain pulp debris and soluble materials.

In the chemigroundwood process, the whole log is cooked before grinding, and the pulp produced has faster drainage and greater strength than the mechanical pulp. At the same time, this pulping process provides better utilization of woodlands, greater fiber versatility, and increased flexibility in the types of pulp produced. Chemigroundwood wastewaters originate in the same sources as in the groundwood process, plus additional wastewaters from the soak pond, after cooking where undesirable chemicals are leached.

Sulfate (Kraft) pulping, utilizing alkaline solutions to dissolve the lignin and other non-cellulous portions of the wood (which cements the cellulose fibers together), has the advantage of producing a high quality pulp of predetermined properties. The digestion process can be accomplished by any one of three methods; direct or indirect batch and continuous direct batch. The continuous techniques have found wide acceptance in new mills while the application of indirect digesting has decreased.

Continuous digestion tends to produce a pulp of more uniform quality, heat losses are reduced (incurred when the digester has to be cooled and filled), eliminates peak steam demands, and reduces corrosion. Even with the disadvantages of low surge capacity and wasted pulp at start-up, the majority of the new mills being built tend to apply this method. Kraft pulping is a cyclic process in which the cooking liquor chemicals are recovered. Because recovery is feasible and practical, water reuse can be practiced to minimize chemical losses.

The major sources of wastewaters from Kraft pulping with chemical recovery systems are digester blowdown, black liquor leaks, spills, overflows, circulating pump cooling and sealing, multiple effect evaporators, dreg washing, (lime mud) washing, white liquor filter washing, and lime kiln and gas scrubbing. There are also three major areas of potential air pollution; the digester blowdown system, multi-effect evaporators, and recovery furnaces.

The acid sulfite pulping processes, based on the digestion of wood chips in an aqueous solution containing metallic bisulfite and an excess of sulfur dioxide, used calcium bisulfite in the older technology without water reuse or chemical recovery. With the advent of more stringent regulations regarding effluent criteria, many mills have sought an alternative base to calcium that would be more amenable to chemical recovery and water reuse. New mills are using either magnesium, ammonium, or sodium base bisulfite; all of which have the advantage of producing a spent liquor that is amenable to chemical recovery and water reuse techniques.

In the older technology, when spent cooking liquor recovery was not practiced, significant quantities of wastewater were generated since the process was essentially a once-through proposition. The newer trends are toward recovery systems designed primarily to reduce pollutional loads. The wastewaters generated, where recovery systems are operating in sulfite pulping operations, will result from spills, leaks, overflows, and cooking liquor preparation, and wastewaters will contain high concentrations of BOD and suspended solids. While wastewaters from soluble based sulfite pulping processes emanate from the digester blowdown, dirty condensate, scrubber shower, acid preparation, chemical losses and recovery furnaces; sources of gaseous wastes are the relief from the digester, emissibns from the evaporators and recovery furnace.

The semichemical process produces pulp and chips using a mild chemical treatment to soften the chips and thereby enhancing mechanical separation of the fibers. Although the pulp yield (80 percent) is much higher than attained from full chemical pulping (45-50 percent), the strength and f exibility is much lower. The two variations of semichemical pulping are the neutral sulfite process (NSSC) and the Kraft (KSC) process, which requires less chemicals and less cooking time than the regular Kraft process. Although semichemical Kraft and Kraft pulping can be handled by the same equipment and facilities, the recovery system for KSC spent liquor is generally combined in the associated Kraft pulp mill. NSSC pulping consists of using sodium sulfate as the cooking agent with sodium carbonate as a buffer. Recently, recovery techniques have been developed for this process. Also, if NSSC pulping is a minor part of a Kraft pulping operation, the NSSC spent liquor can be recovered in the Kraft recovery system and the NSSC cooking liquor made up with fresh chemicals. Semichemical pulp wastewaters, with chemical recovery, contain spent brown liquors (with large concentrations of BOD and suspended solids), digester blowdown, evaporated condensate, and liquor preparation.

Wood and other fibrous plants are not the only source of fiber as both rags and bagasse pulp are in demand. Although all chemical pulping processes are applicable when pulping bagasse, the Kraft or modified soda process with extra sulfur usually give the best results.

Since wastepaper can be reused, deinking facilities are often provided in the pulp mill. The chemicals used, the procedure followed, and the equipment employed in the deinking operation may vary considerably since the process sequence depends on the composition of the grades of wastepapers used, the character of the printing inks, and the final usage of the recovered pulp. Previously, when ample water was available and there was little pollution control enforcement, mills did not reuse wastewater resulting from this process. Present day technology is toward the use of washers in series with proper water reuse with a very definite saving in water, heat, and chemicals. No profitable chemical recovery method has been developed for these wastewaters which contain ink, clay filler, plus the chemicals used in the process.

Digester blow is the process used to blow out the cooled digester contents into a blow tank or tower where the vapors are separated from stock and spent liquor. It is not generally considered a fundamental process but as a process associated with pulping. Because it is one of the main sources of wastewater, it is also the principal source of spent liquors for recovery systems.

Pulp washing is the process designed to remove the liquor and other foreign materials from the pulp, using either diffusers or rotary drum vacuum filters. Vacuum filters have practically eliminated the application of diffusers in modern mills. With the development of a series of washers or multistage countercurrent washing, water requirements have been reduced considerably, with a subsequent reduction in wastewater loadings and quantities. Future developments may be the further combination of pulp washing, thickening and screening, and perhaps eventually, a completely closed system.

The objective of pulp screening and cleaning is to separate the coarse fiber from the fine fiber and to remove dirt and foreign matter. Coarse screens are used in one operation and fine screens in another segment of processing. Centrifugal cleaning is also frequently used to remove dirt etc. that have passed through the screens. All three operations are high consumers of water and recycling of used water is an important in-plant method of reducing wastewater quantities.

The thickening, or dewatering, process concentrates the screened pulp in order to increase its consistency, and the water thus removed is returned and used to thin fresh stock. Some mills still sewer this wasted water. The thickeners generally used are deckers or vacuum filters; the decker being used in the older technology with vacuum filters being used in more modern installations.

In the older technology, significant quantities of wastewater were produced in the course of pulp washing, screening, and thickening. When the washing process was accomplished by a diffusion system, the screening process consisted of diluting the pulp with fresh water and passing the diluted slurry over a vibrating screen, using fresh water both to dilute and transport the pulp. All once-through waters were sewered. Large quantities of water that were used in the decker operation were also sewered.

To brighten the pulp, pulp bleaching is necessary, and the bleaching operation sequence depends on the type of pulp bleached and the end product to be produced. The tendency is toward two-stage peroxide-hydrosulfite bleaching for the groundwood, semichemical as well as the cold soda pulps. The Kraft, sulfite, soda, and NSSC processes require multistage bleaching, using various bleaching agents and caustic extraction. After each stage in multistage bleaching, a washing cycle is necessary. Therefore, water reuse is vital since 3 to 5 stage bleaching operations are quite common. Single-stage hypochlorite bleaching is frequently used when bleaching deinked pulp when the groundwood content does not exceed 10 percent. Multistage bleaching is required when the groundwood pulp content exceeds this limit.

Chlorination of chemical pulps is a rapid reaction and alkaline extraction frequently is necessary after chlorination for sulfate and neutral sulfite pulps (can be omitted with sulfite pulps). Oxidative bleaching of chemical pulps has been practiced for decades.

Although greater brightness can be achieved if smaller amounts of bleaching agent are applied in successive stages with washing between each stage, the resultant increase in water usage (as well as capital costs and fiber loss) is a limiting factor. With the development of chlorine dioxide as a bleaching agent, many modern bleach plants use only five stages to produce very white, strong pulps. The effective reuse of water in multistage bleaching has been helpful in reducing wastewater flows from this area. Wastewaters that are discharged from the bleaching operation are generally characterized by large concentrations of BOD, dissolved solids, color and unreacted chlorine.

Stock preparation is the process of treating the pulp mechanically and sometimes chemically with the use of additives to prepare the pulp for forming into a sheet on the paper machine. There is a series of operations covered in this phase; preparation of the furnish, beating and refining, machine chest mixing, and screening. All operations require water, but water reusage has eliminated a large portion of the water that was previously wasted to the sewer. The wastewater that is discharged to the sewer is primarily contaminated by rejects and cleaners; equipment cleaning wash waters and dumps of furnish that do not meet quality standards or have been damaged in some manner.

Other operations that occur during this process are the addition of fillers (or loading), sizing, wet strength resins, and coloring, all of which are usually diluted in water prior to being added to the furnish.

At the paper machine, the fiber suspension is converted into a paper sheet in three steps: 1) the random arrangement of the fibers into a wet web (paper machine wet end), 2) the removal of free water from the wet web by pressing; and 3) the progressive removal of additional water by heat (paper machine dry end). In older mills, using Fourdrinier machines, the white water resulting from machine (wet end) wire cleaning was sewered, but now individual trays and suction boxes are used to keep rich white water separated from relatively clean waters. The relatively clean white water is eventually recycled to mix with the incoming pulp while suction box white water is used to dilute the stock or as a spray on the wires. The balance of the white water is pumped to a saveall tank. Saveall is a recovery system wherein 95 percent recovery of the fibers and fillers is possible.

Additives can be added on the paper machine, in the coating operation or in the supercalender. Some wastewater reuse is practiced, but the majority is ultimately discharged to the sewer. The quantity of wastewater associated with pulp recovery is small and insignificant in the overall wastewater abatement program, but some solid wastes are generated.

Water is used to convey by-products and undesirable wastes to the incinerator where it is used to generate power and steam. When considering all the water used in pulp and paper mills, the quantity of wastewater generated would be tremendous without water reuse. Data indicate that water reuse accounts for 260 to 320 percent of the water intake for an integrated Kraft or sulfide mill, with Kraft pulping having the highest percentage of water reuse.

Each mill has its own approach as to how to best reuse water in various operations. However, the following waters are the ones most frequently collected and reused:

1. Water from the log flumes and debarkers.
2. Evaporated condensates from liquor recovery area.
3. Washer water from coarse screens.
4. Bleach plant washer filtrate.
5. White water from the paper machine.

Each fundamental process contains a number of operations which can be modified in varying degrees; a subprocess is defined as an alternative technique for accomplishing a fundamental manufacturing process. However, the complexity of the fundamental processes is influenced by many factors; the species of wood being used, the necessity of varying the pulp process in relation to the final product being produced, and the selection and control of the bleaching operation to attain the different degrees of brightness.

Although the fundamental processes and subprocesses of the paper industry are well understood and categorized, the data concerning the percentages of plants employing the particular processes or combination of subprocesses are scarce. Percentages of subprocesses currently being applied are based in some cases on the number of production units instead of the number of plants that have adopted the subprocesses. This was done in order to present meaningful data and to predict future trends.

Subprocesses with difficult wastewater control problems are the pulping, bleaching, and paper machine operations. The spent liquor from pulping is a major contributing factor in wastewater treatment because of its characteristics: high in BOD, depressing effects on the efficiencies of BOD removal in the activated sludge treatment plant, and the large amount of color in the effluent. Problems associated with black liquor from the Kraft process can best be handled by internal liquor recovery systems in which the chemicals are recovered while the BOD contributing organic material and lignin are burned. The sulfite pulping process has the same difficulties as the Kraft process with one additional problem: normal chemical recovery methods are not generally applicable. They complexity and technical problem involved in the liquor recovery are dependent upon the base being used. Problems engendered by the spent liquor from semi-chemical pulping are similar to those encountered with the sulfite spent liquor. Wastewaters from bleaching operations contain high concentrations of BOD, dissolved organic and inorganic material, and are relatively difficult to treat. Wastewaters from the paper machine operation contain fine suspended solids from the sizing and coating operations as well as fiber lost to the waste collection system. Air binding, slime buildup, and chemical corrosion are problems associated with white water reuse systems. Degradation of additives used in stock preparation sometimes result in a higher rate of wastewater discharge from the recirculation system.

Since many of the existing plants limit technological improvements to specific areas of the fundamental processes, it is not uncommon for a mill to employ older technology in one process and newer technology in another area. Clear-cut designation of a plant into one of the technological levels is often difficult. The percentage of mills with process streams that fall into one of the three categories based on overall performance has been estimated for the years 1963, 1972 and 1977, and data is presented in the following table.

Technology Levels	Percent of Plants in Year 1963	1972	1977	Range of Plant Sizes tons/day
Older	24	11	6	20-500
Today's Typical	68	58	48	100-1,000
Newer	8	31	46	200-1,500

The trend is toward establishing larger mills. On the average, mills producing less than 250 tons-per-day are considered small, 250 to 700 tons-per-day mills are considered medium, and more than 700 tons-per-day mills, large. A relative proportion of small, medium and large mills included in each technological level was not readily definable because of the complexity and the number of process variations. However, production per day is not the only major factor in determining an integrated mill size since the pulping process utilized can be a deciding factor in size classification.

Data regarding waste quantities and wastewater volumes associated with the fundamental processes and subprocesses for the three technological levels have been assembled. The units used for wastewater quantities are pounds of waste (suspended solids, dissolved solids, and BOD) generated per ton of product. Data reflect the various degrees of water reuse employed in mills; and in some instances, data in reference to a particular subprocess are not strictly accurate since complete segregation of wastewaters before they reach a common sewer is not possible, particularly when water from one process is being reused in another operation. Type and concentrations of contaminants present result from both operations and cannot be pinpointed to any one individual source. Available data were used to indicate the total waste quantities and wastewater volumes for the bleached sulfate (Kraft), unbleached sulfate (Kraft) and bleached sulfite processes as generated in plants representative of each technological level. Both wastewater quantities and loadings (suspended solids, dissolved solids, total solids and BOD) are effectively decreased as the mill's technology goes from the older to the present to the newer methods. Percentages of mills within one group are 24, 68, and 8 percent respectively. Although the quantity of wastewater generated per ton of product produced decreases as improved methods are developed, the total quantity of wastewater generated will increase due to expanded production. In mills employing the newer technology, the major sources of wastewater in terms of quantities will be Kraft causticizing and blow tower operations; sulfite digester and pulp washing, thickening, and cleaning operations; sulfate and sulfite bleaching; and paper machine operations in all fundamental processes.

Paper production by month does not vary significantly, and consequently, the amount of wastewater generated will only vary at the same rate.

The waste reduction practices employed in the pulp and paper industry are water reuse, chemical recovery, fiber and solids recovery, and technological improvements. The wastes associated with subprocesses typical of "older" technology levels are used as the bases of determining the percent of waste reduction and the extent to which a given subprocess, or subprocess modification, may reduce waste production relative to alternative subprocesses. Areas where significant reductions can be achieved by water reuse or process modifications are tabulated below:

	Wasteloads Reductions Percent	Wastewater Quantities Reductions Percent
Wood Preparation		
Water Reuse	80-90	70
Long Log	95	85
Pulping Process		
Water Reuse	30	30
Liquor Recovery	60-90	60-90
Pulp Screening		
Water Reuse	20-60[1]	20-60[1]
Washing and Thickening		
Use of Vacuum Filters	20-60	20-60
Multistage Countercurrent V.F.	60-90	60-90
Bleaching		
Water Reuse and Recirculation in Multistage Operation	30-80	--
Paper Machine		
Fiber Recovery and White Water Reuse	20-70	60-80

[1] Present level of reduction. Complete elimination of wastewater discharge is attainable if wastewater discharged from coarse screens is returned to the pulping process and if local recirculation is provided at the fine screens.

Areas where mill wastewaters can be reused and the source of such wastewaters are given below:

Fundamental Process	Wastewater Source	Reuse Areas	By-Product Recovery
Wood Preparation	Evaporator Condensate, Bleach plant pulp washer filtrate.	Log flume, hot pond, debarker. Showers	
Kraft Pulping	Condensate from recovery evaporators and heat exchangers, smelt dissolving Underflow from Turpentine separator.	Dilution water; causticizing, screening, deinking, and wood preparation. Lime and shower system.	Turpentine from Digester Relief
Soluble-base Bisulfite			Chemical Recovery from spent liquor.
Paper Machine Operations	White water from Paper Machine	Paper machine, stock preparation, bleaching, pulp washing and wood preparation.	

Wastewater Treatment Facilities

Facilities provided to treat process wastewaters often fulfill two functions: 1) remove contaminants so that wastewater is suitable to discharge to either municipal sewers or receiving waters, or 2) improve the water quality so that it is satisfactory for reuse in the plant. Four functional groups that are included in wastewater treatment practices are: pretreatment, primary, secondary, and tertiary treatment.

Pretreatment

Proper segregation and collection of wastewaters as related to wastewater characteristics are important in determining the treatment sequence. In-plant recovery and controls also contribute to the ability of the treatment facilities to adequately treat wastewaters generated at a minimum cost. Pretreatment is generally required for the main mill flow and can include removal of grit, debris, inorganic ash, sand, gravel etc. This is usually accomplished in a grit chamber (gravity settling tank), and by screening. For proper control of the secondary treatment facilities, pH adjustment (pH range of 6.0 to 9.0) is frequently necessary; hence, neutralization facilities are an integral part of pretreatment. However, the selection of a neutralization method is a function of the separation of process wastewater flows; alkaline and acidic. For example, the alkaline ash wastewaters from the power plant and lime recovery operation can be used to neutralize the acidic wastewaters generated in sulfite pulping. Where Kraft pulping process is being used, such a combination is not possible since the pulping process wastewaters are alkaline. The neutralization facilities, therefore, have to be designed in accordance with the type of wastewater generated by a fundamental process.

Since temperatures of over 100°F can upset the biological treatment in the secondary facilities, cooling is another pretreatment requirement that can be accomplished in cooling towers, spray ponds, cascade channels, and equalization ponds.

Primary Treatment

The basic function of primary treatment is the removal of suspended solids. In the pulp and paper industry, large amounts of colloidal materials and dispersant-type chemicals may tend to inhibit gravity settling, and flocculation can be used to condition the wastewater prior to primary clarification. The addition of flocculant aids is often necessary. After flocculation, the wastewater can be clarified by gravity settling or dissolved air flotation. Only the BOD related to organic and fibrous materials is removed during this treatment cycle. Lignin based color is not removed unless it has been adsorbed on the floc which settles out of the wastewater.

Equalization facilities are frequently provided between primary and secondary treatment plants to control variations in mill wastewater flows and characteristics. These are usually large enough to act as storage tanks in case of mill upsets, or when operating difficulties within the treatment plant limit the amount of wastewater that can be treated.

Secondary Treatment

The primary purpose of secondary treatment is to remove soluble BOD, and for pulp and paper wastewaters nutrient addition in the form of phosphorus and nitrogen is needed to achieve the optimum operation of the biological treatment plant. The conventional activated sludge process can achieve a high degree of BOD removal in the treatment of pulp and paper industry wastewaters.

To function properly, the activated sludge process requires defined and/or controlled BOD loadings, sufficient oxygen supply, and adequate time for completion of the oxidation and synthesis reactions. It is implemented by contacting the mill's wastewaters with an acclimated biological population in the presence of dissolved oxygen. A variation of this system is the contact-stabilization method wherein the acclimated biological organisms are contacted with the wastewaters to accomplish BOD removal, and the settled organisms are returned to a separate aerated stabilization basin where the synthesis reactions are completed. Another method used is trickling filters where the biological growths are attached to the filter media which remove the waste organic material from the wastewater.

Mill Classification	Secondary Treatment Process	BOD Removal Across Process Percent
Integrated Sulfite Mill	Conventional Activated Sludge	85
Integrated Kraft Mill	Contact Stabilization	85

The biological organisms are generally removed in secondary clarifiers by gravity settling. Recently, peripheral-feed, suction sludge draw-off clarifiers are becoming more popular.

Lagoons or stabilization ponds, where low concentrations of biological solids are maintained, can remove BOD; and if improved floating-type aerators are used, clarification prior to discharge to the receiving stream can often be eliminated. Since space requirements for scientifically designed oxidation ponds are normally in excess of land area available, these ponds have found limited application except in the Southern states where the climate favors such a treatment approach.

Irrigation disposal is a form of secondary treatment but is not generally employed in the pulp and paper industry. If used in forested areas with favorable soil and geological conditions, 60 to 95 percent removal of BOD has been achieved during warm, dry weather.

Tertiary Treatment

Tertiary treatment is used to obtain additional removals or "polishing" of wastewaters prior to discharge. To date, the industry has not applied tertiary treatment for removal of lignins in the form of dissolved color or bacteria, but laboratory studies are being conducted. Processes being investigated include: holding ponds and filtration for the removal of BOD and COD; chlorination or ozonation for removal of bacteria; activated carbon adsorption, mass lime and other chemical adsorption processes for color removal and foam reduction; and removal of inorganic solids using electrodialysis, reverse osmosis, and ion exchange.

Sludge and Strong Wastes Disposal

The sludge that is withdrawn from the primary clarifier and the excess biological (secondary) sludge are generally thickened by one of several methods; either alone or in combination: secondary sludge (with 60 to 90 percent volatile solids) does not generally gravity thicken well unless mixed with the primary sludge, and thickened by gravity or by dissolved air flotation or centrifugation. The most widely used dewatering method to date has been vacuum filtration with the use of conditioning chemicals when required.

Recent studies and operational data have shown that centrifugation is very effective in dewatering pulp and paper mill sludges both primary alone and in combination with secondary. However, secondary sludge usually requires chemical conditioning (polyelectrolytes) to be dewatered to 12 to 20 percent solids.

Ultimate disposal of the waste sludges is a "solid waste" problem. Previously sludges were disposed to landfilling and lagooning together with other waste material, such as bark, ash grit, and debris. Increased land costs and more stringent regulations have led to the incineration of primary and secondary sludges with solids concentrations of 30 to 40 percent. Mechanical presses have been evaluated to further dewater sludges after vacuum filtration or centrifugation, but success has been limited by the low fiber content of the sludge.

The disposal of strong wastes, such as digester liquor and pulp washer water, is required where recovery practices are not implemented. Deep well disposal is a possibility, dependent upon the quantity of waste and the availability of geological formations that would prevent groundwater contamination. Spray irrigation, after dilution, has also been attempted; but runoff can cause significant damage in the receiving stream because of high BOD and solids concentrations in the liquor and washer water.

Rate of Adoption

Projections regarding the rate of adoption of wastewater treatment practices are based on somewhat limited data, particularly in regard to smaller equipment. A summary of the subprocesses that are presently used and will be more widely applied by 1977 are given in the following table. Although more expensive than vacuum filtration, centrifugation is being frequently applied in sludge dewatering applications; and the number of mills using centrifugation will equal the number using vacuum filtration by 1977. Ultimately, most mill sludges will be incinerated although by-product development studies are being intensified.

Fundamental Treatment Processes and Subprocesses	Rate of Use at Present Percent	Will be Used in 1977 Percent
Pretreatment		
Screening	60	90
Neutralization	40	80
Primary		
Gravity Clarifier	70	90
Secondary		
Nutrient Addition	20	80
Aerated Lagoon	5	25
Activated Sludge	5	30
Secondary Clarifiers	10	50
Tertiary[1]	--	--

[1] Only pilot plant installations now in operation.

Discharge to Municipal Sewers

Discharge of untreated pulp and paper mill effluent to municipal treatment plants has been practiced since 1950, but currently only a small percentage of the industry is following this practice. Governing factors are the proximity of the mill to a sewer system and the ability and capacity of the sewage treatment plant to accept the wastewaters. Combined industrial and sewage treatment facilities have and can operate successfully particularly where pretreatment is provided for the industrial wastewaters. Pretreatment requirements include neutralization to prevent damage to sewage collection system and treatment facilities: addition of antifoam agents to reduce or eliminate the foaming tendency of the industry's wastewaters; control of sulfur compounds that can lead to malodors in the system; and reduction of the suspended solids concentrations. The discharge of the pulp and paper industry's wastewaters to municipal sewers is expected to increase especially when the treatment plant is designed to handle the combined wastewaters. A wider application is not expected, however, because of the tendency to locate pulp and paper mills in rural areas close to raw material sources.

By-Product Recovery

By-product recovery from spent liquors has been successful for turpentine and tall oil while other by-products such as yeast, alcohols, D.M.S.O. and vanillin can be produced more economically from other materials. Bark, according to species, has been utilized in making roofing felts, heating installation materials, and cheap wrapping paper. While from the sulfite spent liquor, by-products include emulsions for insecticides, scaling inhibitors, tanning agents, cement dispersing agents, fertilizers, flotation acids for separation of ores, well-drilling lubricants, extenders in storage batteries, reinforcing agents for rubber, gradients for ceramic industry electroplating, and road binders.

Capital and Operating Costs

As reported by the National Association of Manufacturers and the National Council for Stream Improvement, the replacement cost for wastewater treatment facilities in the total pulp and paper industry in 1966 was $217,000,000. Roughly, 40-45 percent of this figure can be associated with the portion of the paper industry under study in that these percentages approximate the production and number of mills in the study as compared to the whole industry. Sufficient data is not available to assess the replacement value of specific treatment equipment. Therefore, present costs of such facilities must be used to approximate individual replacement values.

Operating costs for specific treatment equipment are not available; however, annual operating costs vary between 7 and 20 percent of the total capital investment in treatment facilities. Of the total operating cost, approximately 20 percent covers operating labor, 25 percent is for maintenance labor and material, 35 percent is for chemicals (primarily nutrients) and miscellaneous supplies, and 20 percent covers electrical power usage.

Using total, or end-of-pipe, discharge data for integrated bleached sulfate and sulfite mills, various specific wastewater treatment processes were designed for small, medium, and large mills: one each with older, typical, and newer production facilities and related treatment technologies. Integrated bleached sulfate and sulfite operations were chosen because they represent major production facilities and discharge wastewaters of differing treatability characteristics. In general, economic life of treatment equipment is 20 to 25 years.

Various systems of treatment and equipment were combined in a treatment sequence when calculating total capital and operating costs for various mill sizes and technologies. These systems varied from primary treatment with low BOD removal efficiency; primary and secondary treatment in the older technology; high efficiency (85 percent BOD removal by activated sludge) secondary treatment, and sludge handling and dewatering in the present and newer technologies. Since the specific treatment costs did not include general construction items, percentage of capital cost values derived by design experience were used for piping and pumping, electrical and miscellaneous structures costs. The following table summarizes the total capital cost data in terms of mill production capacity in tons of product per day (TPD):

Range of Total Capital Treatment Cost/Mill Capacity in TPD

	Integrated Bleached Sulfate Mill	Integrated Bleached Sulfite Mill
Older Technology	$2,890 - 3,840	$1,920 - 3,420
Present Technology	3,140 - 7,140	5,500 - 13,800
Newer Technology	1,900 - 3,120	2,500 - 4,200

The operating costs related to the defined treatment systems were derived from specific and percentage data. Operating labor, chemicals (nutrients only), and power costs were based on specifying operating requirements for each system, whereas maintenance costs were based on one percent of total structural costs, three percent of total mechanical costs, and one percent of total pumping and piping costs. The following table summarizes the total operating costs in terms of mill production in tons of product.

Range of Total Operation Costs/Mill Production in Tons

	Integrated Bleached Sulfate Mill	Integrated Bleached Sulfite Mill
Older Technology	$1.00 - 1.70	$1.00 - 3.12
Present Technology	1.60 - 3.36	3.50 - 7.30
Newer Technology	1.10 - 1.60	1.30 - 2.30

Since cost data for in-plant modifications to reduce wastewater discharge are not available, the total cost of such activity cannot be compared to the reduced costs for wastewater treatment. However, the combined effect of such future in-plant measures will reduce wastewater volumes by about 45 percent and BOD loads by 25 to 70 percent. The resultant savings in treatment costs will vary with mill size. When utilizing most of the projected in-plant measures, treatment cost savings can be similar to relative cost data obtained by comparing generated capital and operating treatment costs for present and newer (representing increased in-plant reduction) technologies. On a per ton of production basis, capital costs were reduced 50 to 65 percent and operating costs were reduced 30 to 65 percent. The total economic picture must consider the cost of in-plant activities which could completely offset the above treatment cost reductions.

Paper Mills
(SIC 2621)
Industrial Wastewater Profile
for the
Department of the Interior
Federal Water Pollution Control
Administration

INDUSTRIAL MANUFACTURING PRACTICES

Definition of Fundamental Manufacturing Processes

The Profile for Paper Mills (except buildings) is to include pulp mills directly associated with paper mills (integrated pulp and paper mills). Because pulp mills are to be discussed in the fundamental process description, it was considered advantageous to discuss an integrated pulp and paper mill rather than to discuss them separately.

An integrated pulp and paper mill can be divided into two basic parts: 1) a pulp mill which includes the fundamental processes of wood preparation, pulping, screening, washing, thickening, and bleaching: and 2) the paper mill which includes stock preparation, paper machine, and converting and finishing. A simplified diagram of the fundamental processes for the pulp and paper industry is shown in Drawing No. 1. Also shown in the drawing are the raw materials used, final products obtained, and the wastes generated in the form of liquids, gases, and solids. A brief description of each of the fundamental and subprocesses is given below, but for a more complete description, please refer to Appendix D.

Wood Preparation

This process is a composite of a series of processes wherein the wood log is debarked, cleaned, and chipped to a uniform size that will facilitate digestion. The operations include the following:

Log Transportation

Log transportation is the movement of the log by conveyers or flumes from the storage area to the debarking facilities. Flumes require large quantities of water, but much of this can be reused if screening and grit removal facilities are provided.

Debarking

The bark is removed from the logs by one of several methods:

1) Mechanical - Mechanical debarking uses cutting or friction to remove the bark from the log. The efficiency is low and the power consumption is high. Water consumption can also be quite high.

2) Hydraulic - Hydraulic debarking uses water jets at high pressure to remove the bark from the logs. Although considerable quantities of water are used, most of it can be recycled.

3) Chemical - Chemical debarking is a process that has not to date satisfactorily been developed.

4) Long Log - This debarking process is the most recent development in improving the efficiency of the debarking operation. The entire log (uncut) is debarked in one operation.

Bark Disposal

Bark disposal methods employed include incineration, composting, and utilization as by-products. To date the most promising method is incineration for heat recovery although it is necessary to use mechanical presses when incineration is part of a wet debarking operation.

Chipping

Chipping is the process of fragmenting the log into uniformly sized chips which are suitable for digestion. To prevent damage to the wood (compression), the knives must be kept very sharp. Operations used in conjunction with this operation include Chip Screening (separation and removal of slivers and under-and-undersized chips) and Chip Recovery (wherein the rejected chips are recovered and reprocessed).

Pulping

Pulping is the process wherein the wood is converted into fibers which are adaptable for use in paper making. Currently, four pulping processes are employed.

Mechanical (Groundwood) Pulp

Mechanical pulping consists of cutting the debarked log into small blocks which are then forced against a grindstone in the presence of water. Water is used as a cleaning agent, as a pulp carrier, and as a lubricant.

Chemigroundwood Pulp

The chemigroundwood pulping process is a variation of the groundwood process. It is adaptable for pulping hardwoods, and its main advantage is that the whole log is cooked as a unit in a cooking liquor consisting of sodium sulfite and sodium bicarbonate. The log is then ground.

Sulfate (Kraft) Pulp

Kraft pulping utilizes a caustic soda and sodium sulfide solution to dissolve the lignin and other non-cellulose portions of the wood which cement the cellulose fibers together. This pulping process has the advantage of producing a high-strength pulp of predetermined properties. The pulp yield is high, but the resultant pulp is quite difficult to bleach to a high degree of brightness. Being a cyclic system, the chemicals are recovered for direct reuse while the dissolving organic residue is burned for steam and power generation.

The digestion techniques used can be classified into three categories-batch and batch injection method and continuous. The majority of the large new mills being built are incorporating continuous digestion because of the economy afforded by constant steam demand.

Sulfite Pulp

The sulfite pulping process is based on the digestion of wood chips in an aqueous solution containing metallic bisulfite and an excess of sulfur dioxide. The primary reaction of the sulfite pulping process involves the solubilization and sulfonation of lignin and the hydrolytic splitting of lignin-cellulose complex. Although the yield is lower than that obtained with the Kraft process, the pulp is more amenable to bleaching and a high degree of brightness can be obtained.

In the past, a calcium bisulfite base was used without water reuse or chemical recovery. New mills (because of more stringent effluent discharge criteria) are using either magnesium, ammonium, or sodium base bisulfites—all of which produce a spent liquor from which it is possible to recover chemicals. Of approximately 60 sulfite pulp mills in this country, all but a few are more than 20 years old; the majority of these are using either calcium-base or ammonium-base process with no practical recovery methods for chemicals or liquor.

Semichemical Pulp

The semichemical process produces pulp from chips using a mild chemical treatment to soften the chips thereby allowing mechanical separation of the fiber. The advantage of this method is a high yield, but the strength and flexibility of the semichemical pulp is low as compared to that produced by the chemical process.

Variations of the semichemical process in current use are (1) the neutral sulfite semichemical (NSSC) pulping wherein the liquor chemicals dissolve the fiber bond in a process that involves lignin sulfonation and hemicellulose hydrolysis; and (2) the Kraft semichemical (KSC) pulping, which does not achieve the degree of lignin removal that is attainable with the NSSC process, but the hemicellulose removal is greater.

The KSC process is generally finding wider acceptance as an associated process in Kraft mills. Results are good with hardwoods and the cooling liquor is a weak white liquor obtained from the associated Kraft mill liquor preparation system.

Blow Tank

A process that is associated with all types of pulping is the separation of the blow vapors from the stock and liquor (digester contents) in the blow tank. It is one of the main sources of wastewater, waste loads and, therefore, is also the principal source of spent liquors for recovery systems.

Deinking

Deinking is the process of treating printed wastepapers for the removal of the printing ink and the recovery of the pulp in a condition suitable for reuse as pulp. In the future, this process may become one of the major sources of pulp as raw materials sources diminish. The chemicals used, the procedure followed, and the equipment employed in this operation may vary considerably since the process sequence depends on the groundwood content of the wastepapers used, the character of the printing inks, the final usage of the recovered pulp. In the older technology, deinking wash waters were a major source of contaminated wastewaters, but today's technology is toward the use of washers in series with proper water reuse. A very definite saving in water, heat, and chemicals may result from reuse of the first wash water in the wasning cycle.

Pulp Washing

Pulp washing is the process designed to remove the liquor and other foreign materials from the pulp. The two types of equipment used in this operation are (1) the diffuser, which has practically been eliminated from use by the vacuum filters; (2) rotary drum vacuum filters, which have been developed wherein a system of two or three washers in series or multistage countercurrent washing produces the desired level of pulp cleaning while permitting the recycling and reuse of the wash waters. One significant disadvantage of vacuum filter operation is that the contact time between the stock and wash water is relatively short and does not completely remove spent chemicals from the pulp by leaching and diffusion.

Liquor Recovery

Cooking liquor recovery was developed in order to reduce the cost for cooking chemicals and reduce the wastewater loads being discharged to streams. The recovery technique is different with each type of pulping method.

Kraft Liquor

In the modern technology, an essential part of the pulping process is the liquor recovery system. A major part of the chemicals in the spent cooking liquor (known as black liquor), can be recovered in a series of operations; evaporation, burning, and causticizing. The dissolved organic residues from the wood resins can be used for heat and power generation. However, because some soda is lost in the washing operation, salt cake is added to the recovered liquor as it enters the furnace where the salt cake is reduced to sodium sulfide in the combustion process.

Sulfite Liquor

Sulfite liquor recovery techniques are more complex and difficult than those employed in the sulfate system. In fact, the feasibility of liquor recovery is dependent on the base involved in the sulfite liquor. It is generally conceded that recovery is not practical with the calcium base. When a magnesium base is used, the spent liquor is evaporated and burned, and chemicals recovered for reuse. However, for the sodium base, it is possible to recover the inorganic chemicals with a fairly complex process. Spent chemicals from the ammonium base sulfite pulping process can only be partially recovered, but the process does not appear economically promising.

Semichemical Liquor

Liquor recovery in the NSSC process is practiced in some independent NSSC pulp mills using a complicated carbonation method. In the integrated semichemical-Kraft mills, the recovery system is also integrated. The "cross recovery" method is based on the sodium and sulfur values in the NSSC liquor that can be used as chemical makeup in place of salt cake. The NSSC spent liquor can be combined with Kraft liquor for evaporation and combustion, but the NSSC cooking liquor has to be made from fresh chemicals.

The KSC spent liquor is recovered in the same process that is used in a regular Kraft pulping process.

Pulp Screening and Cleaning

Separating the coarse fiber from the fine fiber and removing dirt and foreign matter from the pulp is a vital necessity. Two screening operations used (and these are not usually in a direct sequence) are coarse and fine screening. Frequently, coarse screening is followed by washing, thickening and dewatering; after which the fine screening operation removes more finely sized debris.

In neither of the screening operations are the small dirt and grit particles removed; therefore, another cleaning process is used to remove such material, usually a centrifugal cleaner. Placement of the cleaners in the pulping sequence varies with the function to be performed by the cleaner.

Thickening and Dewatering

The thickening or dewatering process is used to concentrate the screened pulp and to increase its consistency. The water removed is usually returned to be reused in diluting fresh pulp for screening or is wasted to the sewer. The thickeners used for integrated pulp and paper mills are generally deckers (older technology) and vacuum filters (today's technology).

The vacuum filter used for thickening is essentially the same as that described previously for pulp washing. Its advantages over the decker include reduced floor space requirements, fiber loss, and maintenance costs. In many mills pulp washing is incorporated into the vacuum filter thickening operation, and this is particularly true for the multistage, countercurrent systems.

Bleaching

The objective of the pulp bleaching process is the production of a brighter pulp, as measured by light reflectance. To obtain a white pulp, the light-absorbing substances present in the wood pulp (lignin, resin, metal ions, and non-cellulose carbohydrate components) must be removed or chemically changed to reduce their light-absorbing characteristics.

The bleaching operation and sequence depends on the type of pulp being bleached and the end-product being produced. The tendency is toward two-stage peroxide-hydrosulfite bleaching for the groundwood, semichemical as well as the cold soda pulps. Requiring multi-stage bleaching, using various bleaching agents and caustic extractions, are the Kraft, sulfite, soda and NSSC processes. A washing cycle is required after each stage in multistage bleaching; therefore, water reuse is vital since three to five stage bleaching operations are quite common. Single-stage hypochlorite bleaching is frequently used when bleaching deinked pulp when the groundwood content does not exceed 10 percent.

Two types of water recirculation can be used in the bleach plant: (1) within the individual stage where the filtrate from the washer seal box can be reused to dilute and convey the stock going to that same washer; and (2) a transfer of excess filtrates from the final washer seal boxes to earlier stages in the bleach sequence, thus maintaining a countercurrent flow of filtrate from the bleached end toward the unbleached end of the operation. The use of fresh water in the showers assures that the sheet going into each bleaching stage will be relatively free from dissolved organic matter. For maximum water conservation, only the overflow from the chlorination and the first caustic extraction stage are sewered.

It is important when reusing white water from the paper machine in a bleach plant to consider not only the quality of the water and the dissolved material content but also the temperature and the fiber content.

Stock Preparation

Stock preparation is defined as that part of the pulp and paper making process in which pulp is treated mechanically, and often chemically, using additives to make it ready for forming into a sheet on the paper machine. Stock preparation in a paper mill includes all intermediate operations between preparation of the pulp and the fabrication of the paper, and would consist of: 1) preparation of the furnish including consistency regulation and proportioning; 2) beating and refining; 3) machine chest mixing; and 4) screening. Furnish is the term used for the mixture of water, pulp, and chemicals which ultimately goes to the paper machine for fabrication into paper, its composition varies according to the grade of paper being made. The various stocks which make up a multi-stock furnish can be proportioned by many different methods; most prevalent being the use of a multi-compartment stock regulating box.

Fillers, or "loading", are included in the furnish to give paper increased opacity, brightness, bulk, weight, flexibility, softness, smoothness, or printability. These, generally added in a slurry form to the beater during stock preparation contribute greatly to the contamination of the wastewater stream from this area. Only a small percentage of the material actually remains on the paper.

Sizing, wet strength resins and coloring are all generally added prior to feeding the stock to the paper machine. Each of which can substantially contribute to the wastewater contamination.

Pulp stock is prepared for formation into paper by two general processes, beating and refining, but there is no sharp distinction between these operations.

Refining is a mechanical treatment that can be used alone or after beating. It contributes to fiber separation, fiber brushing, and fiber shortening, where the objective is to improve formation and to better adapt the fibers for forming on the paper machine. Because of continuous operation, refiners are now used almost exclusively in large tonnage paper mills. After refining, the stock is retained in a machine chest to insure a uniform consistency of the stock being fed to the paper machine.

Prior to the stock being formed into paper sheets, the stock must be cleaned. Usually, this is accomplished in a rotary type screen and in centrifugal cleaners if finely size dirt and grit particles are present.

Paper Machine Operation

Converting the fiber suspension into the paper sheet involves three steps: 1) the random arrangement of the fibers into a wet web (paper machine wet end); 2) the removal of free water from the wet web by pressing; and 3) the progressive removal of additional water by heat (paper machine dry end). Two types of paper machines are currently being used: the Fourdrinier and the cylinder machines.

The stock, containing about one half percent fiber, is sent through the screens to the headbox of the Fourdrinier machine, and flows from there through a sluice onto a moving, endless wire screen. Nearly all the water and half the fibers pass through the wire to be caught by the wire tray or to fall into the wire pit. Spray water used to keep the wire clean also drains into the wire pit while the water from the wire tray (the rich white water) flows into the mixing well where it is mixed with incoming stock and pumped back into the headbox. Water from the wire pit is used to maintain the water level in the mixing well but the balance is returned to the saveall system where fibers are reclaimed. (Saveails are essential for the reuse of water and for the recovery of fiber, additives, pigments, and other paper making chemicals which otherwise might increase the pollutional loadings to the receiving stream.)

The paper sheet is about 15 to 20 percent consistency after it leaves the suction boxes. Both the wire and sheet move to the first felt blanket which carries the sheet through a series of press rolls where more water is removed and the paper is given a watermark, if one is required. As the paper then passes through steel smoothing rolls, it is picked up by the second felt which carries it through a series of dry rollers which are heated by steam. The paper leaves this area 90 to 94 percent dry. In the calender stack, a series of smooth, heavy-steel rolls, the final surface is imparted to the paper.

In the cylinder machine, the layers of wet paper are passed from one cylinder to another until a composite wet sheet is built up which is then passed through press rolls to the drying and smoothing rolls.

In today's technology, tab sizing, coloring, and coating can all be made a part of the paper machine operation. Consequently, the wastewaters generated in this area can vary according to the processes being used in this operation.

Finishing and Converting

Finishing operations refer to those operations which are performed in the paper mill finishing room and which are needed to prepare the paper for shipment. These include: 1) supercalendering to improve the surface finish; 2) secondary slitting and rewinding to produce rolls sized to the customer's specifications; and 3) cutting the paper into sheets if the end product must be in sheet rather than roll form.

Converting operations cover the modifications of the raw paper from the mill rewinder which will improve the grade of paper with special properties or the fabrication of the paper into a finished article. Two distinct types of converting are used in today's technology: wet converting wherein the paper is handled in the roll form and modified by such operations as coating, impregnating, and laminating. In dry converting, a finished product is made from the paper.

Most of the finishing and converting operations are performed under dry conditions and produce little liquid wastes except in the case of the coating operations. (Mineral or pigment coating improves the printability of paper) while greaseproof lacquer coatings and a wide variety of synthetic resins are used in protective coatings.)

Significant Water Wastes

In the industry on the whole, the most significant wastewater sources are wood preparation, pulping, pulp washing, screening and washing, bleaching, paper machine, and coating operations. Solid and liquid wastes are generated from the transporting and debarking operations involved in the wood preparation. Solid wastes collected at the disk screens and grit chambers contain coarse and fine pieces of bark, wood slivers, and grit. When the bark is incinerated, it is converted to gases, particulates, and ashes. Liquid wastes contain large amounts of dissolved solids from the sap of washed wood.

Wastewaters generated in the mechanical pulping process are primarily from the grinding operation where water is used to cool, clean, and lubricate the surface of the grindstone as well as to convey the pulp out of the grinder. This wastewater contains wood debris and soluble materials from the wood.

The major sources of wastewaters in the sulfate (Kraft) pulping with a chemical recovery system are the digester blowdown, black liquor leaks, spills, overflows, circulating pump cooling and sealing, multiple effect evaporator, dregs washing, lime mud washing, white liquor filter backwashing, and lime kiln scrubbing.

In addition to the gaseous pollutants generated during Kraft pulping; hydrogen sulfide, methyl mercaptan, dimethyl sulfide, and dimethyl sulfide are produced in the digester blowdown system and in the multiple-effect evaporator. Particulates of sodium chloride, sodium carbonate, sodium sulfate, sodium sulfite, sodium sulfide, sodium hydroxide and carbon, as well as emission gases of sulfur dioxide, hydrogen sulfide, methyl mercaptan, and dimethyl sulfide are generated from the recovery furnace. Calcium carbonate is contained in the lime kiln stack gases.

The acid sulfite pulping reaction involves both sulfonation and acid hydrolysis. In most calcium-base sulfite mills, no provision is made for the recovery of the chemicals. The wastewaters from such installations are composed mainly of the spent cooking liquor which contains high concentrations of BOD and suspended solids. Some mills are equipped with facilities to recover the heat generated from the combustion of the concentrated spent liquors. Very high wasteloads are also produced from the digester blowdown, the dirty evaporator condensate, and the furnace ejector. The production of by-products from spent liquor reduces the overall load but generates a wastewater stream with high concentrations of BOD and suspended solids.

For the soluble-base sulfite mills, an efficient recovery of cooking chemicals can be achieved. The main sources of wastewaters are the digester blowdown, dirty condensate, scrubber shower, acid preparation, and the chemical losses from the recovery furnace. The wastewaters discharged to sewers are acidic and contain high BOD and COD concentrations. Dirty condensate waters have a high temperature and can be considered as thermal wastes. The sources of gaseous wastes are relief from the digester, emissions from the evaporators and recovery furnace. Generally, the waste gases contain sulfur dioxide, carbon dioxide, acid fumes, and the particulate matter from combustion end-products. The end-products are $CaSO_4$ for calcium-base, MgO and SO_2 for magnesium-base, Na_2S and Na_2CO_3 for sodium-base, and NO and SO_2 for ammonia-base pulping processes.

Wastewater sources from the semichemical pulping process with liquor recovery are the digester blowdown, evaporator condensate, liquor preparation, and spent brown liquor. Unrecovered chemicals are sometimes wasted from the furnace. The emissions from the blow tank vent and the flue gas from the recovery furnace, contain sulfur dioxide and carbon dioxide. In some instances, the sulfur dioxide in the waste gas is utilized in the sulfiting tower and the carbon dioxide is used to carbonate green liquor to form hydrogen sulfide. When this is done, the exit gases from the sulfiting tower and carbonation unit become the major sources of air pollutants consisting of sulfur dioxide, carbon dioxide, and hydrogen sulfide.

Significant amounts of wastewaters are produced in the course of pulp washing, screening, and thickening.

In the older mills, the washing process is accomplished by a diffusion system where large quantities of fresh water are used and wasted. Screening is performed after diffusion washing, and large quantities of water are used for dilution of pulp and washing of screens. Since little water is reused, most of this once-through water is discharged to the sewer. Solid wastes, containing uncooked wood, knots, etc., are produced from this screening process.

Wastewater from decker thickening constitutes one of the major streams in the pulp mill, but some mills do recycle wastewater from the decker for use in the screening operations. When this is done, wastewater produced from the decker is decreased but the amount wasted at the screens is increased.

Currently, the use of vacuum filters for pulp washing has significantly reduced the quantity of wastes generated. Most of the screening rejects are sent either to the recovery furnace for burning or to the digester for recooking. Since in recent years multistage vacuum filtration has been used for both washing and thickening, wastewater from separate thickening operations has been essentially eliminated because of the countercurrent flow and water reuse.

Wastewater sources in the bleaching operations are from the pulp washing operations, which are necessary after each of the bleaching sequences. With the development of the countercurrent type of washing for a series of washers, most of the fresh water is added in the last washing cycle, and wastewaters are usually discharged to the sewers from the first or second washer. The wastewaters are generally characterized by high concentrations of BOD, dissolved solids, color and unreacted chlorine. If possible these wastewaters should be discharged to separate acid and alkaline streams.

Little wastewater is produced in the stock preparation operations except for rejects from cleaners, equipment cleaning wastes, or when a particular stock that has been prepared is discarded.

The white water from the paper machine operation contains fibers and fillers. Using savealls, the current practice is to reclaim the fibers and fillers. The greater percentage of the white water is recycled within the paper machine; excess is used for dilution in stock preparation or reused in a number of other operations in the pulp mill. Even with the present technological developments, a considerable amount of effluent from the saveall systems are discharged to the sewer.

Other wastes of lesser significance are generated from the broke recovery and coating operations.

Process Water Reuse

Large quantities of water are essential in the pulp and paper manufacturing processes. Water is used for pulp processing, washing, dissolving or mixing the various loading, sizing, and color ingredients, carrying the fibers through the screens and refiners to the paper making machine, and operation of the paper machine. Water is also used to convey by-products and undesirable wastes and to generate power and steam. Without water reuse, the amount of wastewater to be discharged would be tremendous. Therefore, the maximum reuse of water becomes one of the basic approaches in the effective reduction of wastewater quantities.

There are definite limits in the amount of mill water which can effectively be reclaimed and reused. Fresh water has to be added in certain operations to prevent the build-up of undesirable dissolved solids, temperatures, and slime from bacteria and fungi growth.

Each mill has its own approach on how best to reuse water in the various operations. However, the following process waters are most frequently collected and reused: 1) water from the log flumes and barkers; 2) evaporator condensate from the liquor recovery area; 3) bleach plant washer filtrate; 4) white water from the paper machine; and 5) washer water from coarse screens.

An accepted practice is the reuse of wastewater in wood handling and storage, such as in the log flumes, hot pond, hydraulic or wet drum debarker, and for the showers prior to chipping. For these applications, heated effluents discharged from evaporators, bleach plant, or paper machine are preferred because the heat increases bark removal efficiency, particularly from frozen wood. Recycling barker effluent, which has been cleaned (grit removal) and screened, is a widely practiced water reuse procedure.

In the pulp mill, after the wood is cooked with chemicals or mechanically ground, the pulp is washed and thickened. The wastewater from the digester usually contains the spent cooking liquor and the condensate from the digester heat exchanger. If the cooking liquor is recoverable, the water can be evaporated and collected as condensate while chemicals are being recovered for reuse in the digestion process. The condensate collected can be used in steam generation, as scrubber water for flue gas, or in the brown stock washing process.

The screening department offers an excellent opportunity to reuse a large amount of waste effluent. Decker or thickener water is often recycled and used as dilution water ahead of the screening and cleaning operation. However, since the washing operation is intended to remove the cooking liquor from the pulp, economics dictate that a considerable amount of the contaminated wash water be displaced by make-up water since this reduces the pulps' chlorine demand in a later operation and also prevents the build-up of dissolved solids which cause salting out and foaming on the screens. The necessary make-up water can be obtained by reusing the pulp mill condensate, bearing and condenser cooling water, paper machine white water, and certain bleach plant filtrates.

In the Kraft chemical recovery process, water can be reused in the following operations: 1) dregs washing; 2) green liquor dilution; 3) lime slaking, lime mud washing, and lime kiln scrubbing; 4) white liquor filter back washing; and 5) scrubbing of flue gases. The primary source of water to be reused in these processes is the evaporator condensate, although some mills are using the liquor, after scrubbing out the solids from the flue gases, for washing dregs and lime mud.

In the sulfite chemical recovery process, the evaporator condensate is used to dilute the soda ash from the furnace and to scrub the flue gases when recovering sulfur dioxide.

The removal of the residue lignin and the washing of the bleached pulp requires a large amount of water in the bleaching plant. The wastewaters generated contain a large amount of color and have a tendency to foam. The amount of fresh water make-up required can be reduced by employing the following water reuse techniques: 1) the use of washer filtrate for dilution of stock leaving the bleaching towers; 2) the use of excess washer sealbox waters in the preceding sealbox washing cycle; 3) the use of white water and excess cooling water to dilute the finished bleached pulp; and 4) the use of digester condensate for shower water, bleaching tower dilution water, and brown stock dilution water.

The source producing the largest quantity of reusable water is the paper machine which generates the white water. The quality of white water is sufficiently high that it can be reused throughout the mill. The tray water from the Fourdrinier machine and the vat discharges of the cylinder machines can be segregated and reused. Fresh water requirements can be further reduced by reusing the unclarified white water in stock preparations, for dilution water, in consistency regulators, and in cleaners, and deculators. To insure that the paper machine excess clarified water tanks will remain clear, it is often advantageous to send machine spills, shutdown and wash-out waters to a separate tank where the solids can be removed and eventually reused; the clear water goes to the clarified tank. Chlorination of the clarified water, which is used to dilute the high-density bleached pulp, can result in a considerable saving in paper machine slimicide costs.

The estimated percentage and quantity of reused water during 1964 are summarized in Table No. 1. These data indicate that water reuse accounts for 260 to 320 percent of the water intake for integrated sulfate (Kraft) or sulfite pulp and paper mills. However, the percentages change radically when calculations are based on the total process water used (fresh water plus the reused water), the range being 63-73 percent.

Table 1

Process Water Reused by Pulp and Paper Industry

	Type of Mill	Bleached Kraft and Paper	Unbleached Kraft and Paper	Bleached Sulfite and Paper	Deinker and Paper
(1)	Fresh Water Intake (gal/ton of product)	45,000	30,000	60,000	33,000
(2)	Water Reused (gal/ton of product)	144,000	78,000	160,000	57,000
(3)	Reuse factor (%) (3) = (2) x 100/(1)	320	260	267	172
(4)	Percent of Mills with Water Reuse	92	78	75	80
(5)	Total Process Water Used (5) = (1) + (2)	199,000	108,000	220,000	90,000
(6)	Percent of the Total Process Water Reused (6) = (2) x 100/(5)	72	72	73	63

Industry Subprocess Mix

Since the fundamental processes described in the previous section contain a number of operations which can be modified in varying degrees, these modifications are considered subprocesses. A subprocess is defined as an alternative technique for accomplishing a fundamental manufacturing process. However, the complexity of a fundamental process is influenced by many factors: the species of wood being used; the necessity of varying the pulping process in relation to the final products to be produced; and selection and control of the bleaching operation to obtain the different degrees of brightness.

From the standpoint of production of pulp, the fundamental pulping process can be classified into five categories: 1) groundwood; 2) Kraft; 3) sulfite; 4) semichemical; and 5) deinking. The first four categories are related to the use of wood logs as a source of raw material, while the last category (deinking) involves the production of pulp by reprocessing of wastepapers. The selection of the process to be used is governed by the final product to be produced. As there are a number of alternative subprocesses for each type of pulping, mills can produce their specialized products if they determine which process and subprocess most completely fulfill their needs.

Although the fundamental processes and subprocesses of the paper industry are well understood and categorized, data concerning the percentage of mills employing a particular subprocess or combination of subprocesses are scarce. Percentages of subprocesses presented are based in some cases on the number of production units instead of the number of plants adopting the subprocesses in order to present meaningful data and to predict future trends.

The industry subprocess mix is presented in Table A-1. Included in the table are the fundamental processes of wood preparation, pulping, bleaching, and paper machine operation. These are considered of prime importance in predicting future technological trends and the type of wastewaters that will be produced. The table does not cover the fundamental processes of pulp screening, washing, and thickening, stock preparation, and paper converting and finishing because no data were available.

As was discussed in the fundamental process section, wood preparation consists of a series of operations: log transportation, debarking, chipping, and chip storage. For convenience of assigning processes according to the three different technology levels (older, present, and future), alternative subprocesses of wood preparation are divided into the following categories: 1) without water reuse, 2) with water reuse, and 3) with long log preparation.

For the pulping operations, different alternative subprocesses are associated with each type of pulp produced. In mechanical pulping, the alternatives are categorized into: 1) groundwood without water reocvery; 2) groundwood or pretreated groundwood with water reuse; and 3) refining mechanical pulp. In the sulfate mill, the pulping process has the following subprocesses: 1) batch digestion without water reuse; 2) batch digestion with water reuse; and 3) the continuous digestion process. The alternatives in sulfite pulping are numerous, but they are grouped into three subprocesses according to the effects exerted on the wasteload and wastewater quantities: 1) calcium-base batch process without water reuse and chemical recovery; 2) calcium-base or ammonium-base batch process with heat and partial chemical recovery; and 3) magnesium or other soluble base batch or multistage process with heat and chemical recovery. When semichemical pulping is being utilized in a paper making operation, its alternatives can be classified into: 1) NSSC batch process without chemical recovery; 2) NSSC or KSC batch process with chemical recovery; and 3) continuous process with chemical recovery.

In the case of bleaching operations, various bleaching sequences are available for each type of pulp. Single-stage hypochlorite bleaching is used for many types of pulps in older mills while modern technology trends show that peroxide-hydrosulfite process is used for groundwood pulp, three-stage bleaching is used for sulfite and semichemical pulp, and five-stage bleaching for the sulfate pulps. In addition to the different bleaching sequences, the problem of water reuse further increases the number of alternative subprocesses available for consideration. Unfortunately, data regarding the detailed breakdown of plants adopting the finely divided alternative subprocesses are not available. Based on available data, the alternative subprocesses of bleaching are most conveniently grouped into the following categories: 1) bleached sulfate; 2) semibleached sulfate; 3) unbleached sulfate; 4) bleached sulfite; 5) unbleached sulfite; and 6) others which include bleached and unbleached groundwood, semichemical, soda, and deinked pulp.

Alternative subprocesses for paper machine operation include: 1) cylinder machine with or without water reuse; 2) Fourdrinier machine without fiber and white water recovery; and 3) Fourdrinier machine with fiber and white water recovery. Data regarding the subprocess mix, as it existed in 1950, 1963 (the base year) and 1967, are entered in Table A-1. Results tabulated for wood preparation, pulping, and paper machine are derived from data in Lockwood's Directories and TAPPI Water Conference Proceedings. Data for the subtotal of each type of pulping and bleaching process were obtained from the Census of Manufacturers, U. S. Department of Commerce.

The projected subprocess mix for 1972 and 1977 was obtained by graphical extrapolation of the earlier data plus opinions expressed by industry personnel concerning the rate of adoption of new technology and the industry's obsolete equipment retirement practices.

Mills with daily production of 700 tons or more are classified as large mills; those with a daily production of 250 tons or less are classified as small mills, and those in between are considered as medium size mills. As the development of fundamental manufacturing processes is relatively unaffected by the size of the mill, it is assumed that the differences in mill size have little bearing on the trend of the subprocess mix and wastewater characteristics, although the future trend is toward the establishment of larger mills.

Since 1950 when the Kamyr continuous digester was introduced, most of the newly-built Kraft mills are using this process. Recent developments in the sulfite process are toward high-yield pulping at a higher pH (bisulfite instead of acid sulfite). It is predicted that the liquor recovery in sulfite pulping will become one of the major factors determining the future of the sulfite mill from the standpoint of pollution abatement and the economic justification of the chemical costs.

From Table A-1, it can be seen that the bleached sulfates are gaining predominance over all other pulping processes, and that unbleached sulfate and bleached and unbleached sulfite processes are decreasing in relative percentage of production. Semichemical pulp is gradually increasing in use, yet remaining at a very low production rate. Groundwood (mechanical) pulping and deinking are maintaining about constant proportions of total production.

In addition to the above subprocess mix, the relative percentages of pulping processes as related to other paper products for the year 1963 are shown in Table A-2 to illustrate the complexity of the problem. From this table, it can be seen that each of the pulping processes is distributed in a variety of ways in order to make almost all types of paper products. The percentages shown are based on the total paper products in tons.

It should be re-emphasized that the paper products considered are for the Standard Industrial Classification No. 2621 only. Other types of products, such as paperboard and building papers which are classified under other SIC numbers, are not included. During 1963, a total of approximately 40 million tons of paper and board was produced, of which 17.5 million tons were for paper products (SIC 2621). It can readily be seen that a considerable amount of pulp is used for the manufacturing of board and building paper.

Subprocesses With Difficult Waste Control Problems

The pulping process is a consistent problem source in connection with pollution control. In sulfate pulping, the unrecovered black liquor is a major contributing factor in wastewater treatment because of the following characteristics: 1) high BOD concentration in the order of 100,000 mg/L for 15 percent solids black liquor; 2) depressing effect on the efficiencies of BOD removal in the activated sludge treatment of combined effluent; 3) a very high color content of about 400,000 platinum-cobalt units for 15 percent solids black liquor; and 4) a high foaming potential that readily offers visual evidence of pollution. Typical foaming potential is 2500 ml. of foam per liter of 0.15 percent solids black liquor. Reduction of problems associated with the black liquor from Kraft pulping is best achieved internally by a liquor recovery system in which chemicals are reclaimed, while BOD-contributing organic materials and the color-causing lignin are burned.

In sulfite pulping, the difficulties encountered in pollution control also emanate from its spent cooking liquor. Many calcium-based sulfite mills continue to discharge their spent liquor directly into the wastewater streams without any chemical recovery or secondary wastewater treatment. The spent sulfite liquor contains very high concentrations of BOD, solids, color, and acidity. Problems caused by the spent liquor from semichemical pulping are similar to those of sulfite spent liquor.

Wastewaters from bleaching operations contain high amounts of BOD, dissolved organic and inorganic material, and are relatively difficult to treat. Bleach plant wastewaters are generally colored by the lignins and tannins which have been removed from the pulp. Cellulose material in the wood fiber, the lignins, and tannins are not easily attacked biologically. Foaming is also a problem associated with the filtrates from the washing cycles in caustic extraction and hypochlorite bleaching stages. Preventing spills and overflows is important in foam control, and will simultaneously increase the efficiency of the washing cycle.

Wastewaters from paper machine operations contain high concentrations of fine suspended solids which may settle slowly in the clarifiers and fine particles may even be discharged in the effluent. Difficulty in the dewatering and volume reduction of wastewater sludge could also be attributed to the fine materials lost from the paper machine operation.

Air binding, slime build-up, and chemical corrosion are problems associated with the white water reuse systems. Degradation of additives, (such as starch and casein) in the white water system has the potential of fouling the entire stock being prepared. These limitations on the reuse of white water will result in higher rates of wastewater discharge.

Three Production Process Streams

The three production process streams include: a subprocess series representative of an older processing technology; a "typical" series of subprocesses which are most prevalent today; and a series representative of a newer processing technology. These three series are shown on Drawing Nos. 2, 3, and 4 respectively. It should be understood that these drawings are representative of various pulping and paper making processes being used at each of the three technology levels, and do not represent a flow sheet of any single mill in actual operation.

A mill is generally classified as belonging to the older technology when the processes employed are relatively inefficient, excessive quantities of wastewater are produced, no recovery of liquors is provided (except for sulfate mill), and little or no wastewater is reused. A representative subprocess series of the older technology which is in use today consists of: 1) wood preparation by mechanical debarking of logs without water reuse and without bark utilization; 2) groundwood, sulfite, semichemical pulping, or deinking without water reuse and without chemical or heat recovery or sulfate (Kraft) with inefficient chemical recovery; 3) screening without water reuse; 4) pulp washing by diffuser and thickening by decker; 5) bleaching without countercurrent water reuse; 6) stock preparation by batch operation; and 7) paper machine operation with little or no fiber reocvery and white water reuse.

A mill is classified under today's technology when the processes employed are the most widely used among the industry, the wastewaters produced are within a typical range regarding both quantities and characteristics, moderate recovery of liquors is employed, and reuse of water is practiced. The representative subprocess series of today's technology consist of: 1) wood preparation by mechanical debarking of logs with water reuse and bark utilization; 2) groundwood or pretreated groundwood pulping from wood logs with water reuse; sulfate (Kraft) pulping by batch process with water reuse and liquor recovery; sulfite pulping by use of calcium-base process with water reuse and heat recovery; neutral sulfite semichemical or Kraft semichemical pulping by batch process with water reuse and liquor recovery; or deinking by cooking and washing, with water reuse; 3) screening with water reuse; 4) pulp washing and thickening by vacuum filtration; 5) bleaching with countercurrent water reuse among stages; 6) stock preparation by continuous operation; and 7) paper machine operation with fiber recovery and white water reuse.

A mill is classified in the newer technology group when the processes employed have been improved and are more efficient, a high degree of water reuse is employed, chemicals and heat are recovered with subsequent reduction of pollution loadings, and effluent wastewaters generated are low in quantity. The representative subprocess series of the newer technology consist of: 1) wood preparation by long log debarking with water reuse and bark utilization; 2) refining groundwood pulping from chips with water reuse; Kraft pulping by continuous process with water reuse and liquor recovery; sulfite pulping by use of a soluble base (such as ammonium or sodium or magnesium) with water reuse, heat and chemical recovery; semichemical pulping by Kraft or neutral sulfite continuous process (often associated with sulfate pulping); or deinking by cooking and washing with extensive water reuse; 3) screening and centrifugal cleaning of pulp with water reuse; 4) pulp washing and thickening by multistage vacuum filters; 5) bleaching with high degree of water reuse within each washer and among stages; 6) stock preparation by continuous operation; and 7) paper machine operation with segregation of white waters according to their quality, and with fiber recovery and extensive water reuse.

Since many of the existing plants limit technological improvements to specific areas of their fundamental process or subprocesses, it is not uncommon for a mill to have older technology in one process and newer technology in another. Clear cut designation of a plant into one of the three technology levels is often difficult. The percentage of mills with process streams that fall into one of these three categories, based on overall performance, has been estimated for the years 1963, 1972, and 1977. Estimated percentages are shown in Table No. 2.

Table 2

Percentage of Plants According to Technology Level and Production Capacity

Technology Levels	Estimated Percent of Plants in Year			Range of Plant Sizes tons/day
	1963	1972	1977	
Older	24	11	6	20-500
Today's Typical	68	58	48	100-1,000
Newer	8	31	46	200-1,500

The mill sizes associated with these three technology levels are also indicated in the above table. It can be seen that the trend is towards the establishment of larger mills. To categorize size relative to pulping process; sulfate Kraft mills are relatively large; while sulfite, semichemical, and groundwood mills are relatively small. In many cases, groundwood, deinking, and semichemical pulping processes are integrated in the sulfate or sulfite mills.

On the average, mills producing less than 250 tons per day are "small", 250 to 700 tons per day are "medium" and more than 700 tons per day are "large". The relative proportion of small, medium, and large mills included in each technology level is not readily definable because of the complexity and number of process series variations. However, production per day is not the only factor determining mill size, since the type of pulping process utilized can also be a deciding factor in mill size classification.

GROSS WASTE QUANTITIES BEFORE TREATMENT OR DISPOSAL

Unit Waste Quantities and Wastewater Volumes

The unit waste quantities and wastewater volumes associated with the fundamental processes and subprocesses for the three technology levels are presented in Tables A-3, A-4, and A-5 respectively for the older, today's typical, and newer technologies. The units used for wastewater quantities are pounds of pollutant (such as suspended solids, dissolved solids, and BOD) generated per ton of product. Each mill has a wide variety of fundamental processes, subprocesses and combinations from which to choose under the older, present, and newer technology; and except for mills being built, it is impossible to estimate the exact operating sequence any individual mill might select, much less estimate the number of mills that would select the same sequence. It is, therefore, impossible to determine wasteloads and quantities for the three mill sizes (small, medium, and large) as related to the different technological levels. Consequently, no data is presented. Variations in wasteloads and quantities according to mill size were not readily obtainable, but significant variations were not expected. However, the data on wasteloads per ton of production was thought to be meaningful for application in any specific mill. Thus, conversion of pounds/ton into pounds/day or gallons/ton into mgd can be easily performed, if the mill production in tons per day is known.

The range, as well as mean values, of the waste loadings and quantities are shown in the tables to indicate significant variations. In many instances, direct data for detailed breakdown of subprocesses were not obtainable. However, data shown in the tables are considered to be representative of each subprocess. When fragmental data or unit datum are available, they are enclosed in parentheses to indicate the probable order of magnitude. In the interpretation of data, it should be understood that various degrees of water reuse have been employed in most mills; and, therefore, are reflected in the data. Complete segregation of wastewaters before they reach one or several common sewers is not possible. Therefore, it is likely that data reported for a particular subprocess wastewater and the contaminants contained therein may also contain wastewaters from other subprocesses. This is particularly true when water from one fundamental process is reused in another process.

Wastewater characteristics related to the cylinder or Fourdrinier paper-making machines were not available. Since wastewater characteristics related to different paper products have been reported in the literature, these have been included in the tables for both the older and today's typical technology.

Total Wasteloads and Wastewater Quantities for Each of the Three Technology Levels

Derivation of total waste quantities and wastewater volumes, which could have been obtained by adding together the estimates for all subprocesses as developed in the previous section, was not attempted. It is considered that the data for the subprocesses listed in Tables A-3 through A-5 should not be used as "additives" because of the complexity of the operations involved in the different pulping processes, various degrees of water reuse from one process to another, and product-related problems.

Instead, total waste quantities and wastewater volume, based on available data covering bleached sulfate (Kraft), unbleached sulfate (Kraft) and bleached sulfite processes, and for each of the three representative levels of technology, are presented in Tables A-3 through A-5. These different types of wastewaters are an important consideration in the design of wastewater treatment facilities which are to be discussed in later sections.

It should be mentioned that groundwood, semichemical and deinked pulps are frequently incorporated in the sulfate (Kraft) or sulfite mills. Therefore, data available for these processes cannot be considered as typical of any individual type of mill.

Base Year 1963

Total wasteloads and wastewater quantities per unit of product, as produced by mills representative of the three technologies, are summarized in Table No. 3. Data shown in this table were obtained by compositing the wastes of different pulping processes as shown in Tables A-3 through A-5 for the older, today's typical and newer technology levels. In these tables, total wasteloads and wastewater quantities are shown for bleached sulfate, unbleached sulfate, and bleached sulfite integrated pulp and paper mills. Since these three types of mills constitute the major portion of paper industry production, groundwood, semichemical, deinking, and other types of mills are in the minority. Data regarding wasteloads and wastewater quantities from the latter group are often incomplete. Therefore, estimates covering these were based on data for fundamental processes as shown in Tables A-3 through A-5.

Table 3

Total Wasteloads and Wastewater Quantities by Technology Levels in Year 1963

Technology Levels	Wasteloads lbs/ton of Product Sus. Solids	 Dis. Solids	 Total Solids	 BOD	Wastewater Quantity gal/ton	Est. % of Industry in each Level
Older	130	810	1000	200	84,000	24
Today's Typical	120	550	670	135	40,000	68
Newer	90	260	350	80	25,000	8

Data regarding the relative number of bleached sulfate, unbleached sulfate, bleached sulfite, unbleached sulfite, groundwood, semichemical deinked, and other types of mills listed in Table A-2, were utilized in calculating the wastes composites for each of the technology levels for the year 1963.

Gross Wasteloads and Wastewater Quantities Produced by Industry in Base Year 1963

The gross wastes and wastewater quantities produced by the paper industry in base year 1963 based on the estimated percentages of industry employing the three technology levels and the product value added in 1963 are shown in Table No. 4 on the following page.

Table 4

Gross Wasteloads and Wastewater Quantities in Year 1963 - Total Industry

Items	Wasteloads, lbs				Total Wastewater gals.
	Suspended Solids	Dissolved Solids	Total Solids	BOD	
Wastes/Ton of Product	135	590	725	150	49,500
Gross Wastes in 1963[1]	2.36×10^9	10.3×10^9	12.7×10^9	2.62×10^9	868×10^9
Wastes/Dollar of Product[2]	1.20	5.25	6.45	1.33	452

[1] Based on 17,500,000 tons of paper product produced in 1963.

[2] Based on an adjusted product value of 1,962 million dollars in year 1963. (provided by FWPCA)

Projected Gross Wasteloads and Wastewater Quantities in the Years 1968 through 1972 and 1977

The projected gross wastes and wastewater quantities on the basis of product values provided by FWPCA for each of the years 1968 through 1972 and 1977 and on the estimated percentages of industry employing the three technology levels (See Table 2) for 1972 and 1977 are summarized in Table No. 5.

Seasonal Waste Production Patterns by Month

The wasteloads and wastewater quantities per ton of paper product have been established in the previous sections. Since the paper production and waste production is a direct ratio, seasonal variation in paper production can be used to indicate the seasonal variation in wastewater quantities. Table A-6 shows the monthly production of different paper products in 1964. Ratios of maximum to minimum monthly production are calculated for each type of paper. It can be seen from Table A-6 that for most of the various types of paper, which account for 94 percent of total paper production, maximum to minimum monthly production ratios varied from 1.14 to 1.26. Minor types of paper, such as miscellaneous groundwood, uncoated book, text cover, colored school, sanitary towel, and other sanitary tissue stock wadding papers, had ratios of maximum to minimum monthly production ranging from 1.34 to 2.20. These minor types of paper account for only six percent of total paper production. The ratio of maximum to minimum monthly production for all types of paper was 1.15. Maximum production appeared to fall in the months during spring and late summer. It can be concluded that, except for specialized types of paper, the monthly variations of waste production are within 26 percent of the average for the whole paper industry.

Table 5

Projected Gross Wasteloads and Wastewater Quantities

Items	Wasteloads, lbs.				
	Suspended Solids	Dissolved Solids	Total Solids	BOD_5	Wastewater Quantities gallons
Wastes/Ton of Product in 1972	125	485	610	120	41,000
Wastes/Ton of Product in 1977	120	440	560	110	36,000
Wastes/Dollar of Product in 1972[1]	1.23	4.79	6.02	1.18	405
Wastes/Dollar of Product in 1977[2]	1.29	4.75	6.04	1.18	387
Gross Waste in 1968[3]	$2.82x10^9$	$11.1x10^9$	$13.8x10^9$	$2.71x10^9$	$930x10^9$
Gross Waste in 1969[3]	$2.87x10^9$	$11.2x10^9$	$14.0x10^9$	$2.75x10^9$	$942x10^9$
Gross Waste in 1970[3]	$2.92x10^9$	$11.4x10^9$	$14.2x10^9$	$2.80x10^9$	$960x10^9$
Gross Waste in 1971[3]	$2.96x10^9$	$11.5x10^9$	$14.6x10^9$	$2.84x10^9$	$975x10^9$
Gross Waste in 1972[3]	$3.03x10^9$	$11.8x10^9$	$14.8x10^9$	$2.91x10^9$	$990x10^9$
Gross Waste in 1977[2]	$3.50x10^9$	$12.9x10^9$	$16.3x10^9$	$3.21x10^9$	$1050x10^9$

[1] Based on an estimated production 24,200,000 tons and adjusted production value of \$2,450x10^6 in the year 1972.

[2] Based on an estimated production 29,200,000 tons and an adjusted production value of \$2,712x10^6 in the year 1977.

[3] Based on Wastes per dollar of product in 1972 and adjusted production values of \$2,294x10^6 in the year 1970; \$2,407x10^6 in the year 1971; and \$2,450x10^6 in the year 1972.

WASTE REDUCTION PRACTICES

Processing Practices

Waste Reduction Efficiency

The waste reduction practices employed in the pulp and paper industry are water reuse, chemical recovery, fiber and solids recovery, and technological improvements. The percent waste reduction and the extent to which a given subprocess, or process modification, may reduce waste production relative to alternative subprocesses are given in Table A-7. The wastes associated with subprocesses typical of "older" technology levels are used as bases. In other words, the percent reduction in waste quantities of subprocesses listed in "typical" or "newer" technology levels are determined by using quantities associated with an "older" technology as a base. These waste reduction percentages were calculated from data regarding the three technology levels shown in Tables A-3, A-4, and A-5.

It is estimated that approximately 80 to 90 percent reduction of wasteloads and 70 percent reduction of wastewater quantities could be obtained by water reuse in the wood preparation processes. Further reduction of wasteloads, up to 95 percent, and wastewater quantities, up to about 85 percent, can be achieved when the long log preparation method is employed.

In the pulping process about 30 percent reduction of wasteloads and wastewater quantities are obtained by water reuse. Waste reductions, ranging from 60 to 90 percent, could be achieved with liquor recovery.

At the present technological level, waste reductions of 20 to 60 percent in the pulp screening process are obtained by partial water reuse. However, complete elimination of wastewater discharge from this process is attainable in the newer technology if the wastewater discharged from the coarse screens is returned to the pulping process and if local recirculation is provided at the fine screens.

Use of vacuum filter for washing and thickening of pulp can achieve 20 to 60 percent greater reduction in the amount of waste generated as compared with the use of diffuser washing and decker thickening. Further reduction of wastes generated (60 to 90 percent) has been accomplished by the use of multistage countercurrent vacuum filter washing and thickening.

When recirculation facilities are used in the multistage bleaching sequence, 30 to 80 percent waste reductions have been achieved with various degrees of water reuse. Also, 20 to 60 percent of wasteloads and 60 to 80 percent of wastewaters generated can be reduced by fiber recovery and white water reuse in the paper machine operations.

Technological Considerations on Waste Production and Interdependencies Among Processes

The common uses of water in the wood preparation processes are the log flume, hot pond, hydraulic or wet drum debarker, and showers prior to chipping. Since modern technology emphasizes the reduction of total wastewaters generated, the industry has realized that mill wastewaters can replace fresh water in most of these applications. In many cases, the heated effluent, such as evaporator condensate, and bleach plant washer filtrate, are preferred because the high temperatures of these wastewaters increases the efficiency of bark removal from frozen wood.

In sulfate (Kraft) pulping, condensate from the recovery evaporators and heat exchangers can be used for brownstock washing, sprays in the early stage bleach plant washers, smelt dissolving, and as dilution water for processes involved in causticizing, screening, deinking, and wood preparation. Another significant waste reduction is possible through the recovery of turpentine from the digester relief. Since the underflow from the turpentine separator is high in mercaptan and dimethyl sulfide, it can be used in the lime and shower system.

In the sulfite pulping process, using the conventional calcium acid bisulfite, the spent cooking liquor is normally discharged as waste. The difficulties arising from the evaporation and burning of calcium-base spent liquor are due to the scaling tendency of the lime salts, particularly calcium sulfate, upon the evaporator's surface. At the present technological level, this burning process is primarily carried out for the reduction of organic material dissolved in the spent liquor. Therefore, the principal inorganic products of combustion, namely $CaSO_4$ and CaS, are not recovered and are discharged to sewers.

Chemical recovery of spent liquor from sulfite pulping, using ammonium, sodium, or magnesium bases, can be achieved to reduce organic and inorganic waste loadings. Ammonium-base residual liquor can be burned to recover most of the SO_2 plus heat value obtainable.

Sodium-base cooking liquor can be burned with the heat value recovered as steam, while the chemical ash consisting of Na_2S and Na_2CO_3 is recovered in the form of smelt, which can be reprocessed to generate cooking liquor. Magnesium-base spent liquor can be burned to form MgO and SO_2, which can then be recombined to form cooking liquor.

Multistage countercurrent vacuum filters can be used to combine the operations of washing and thickening. At the same time, the system can be completely closed so that no wastes will be lost to the sewer. Wastewater discharged from the first stage washer can be sent to evaporators and then to the furnace for chemical recovery.

Wastewater reduction in the bleaching operations is primarily achieved by recirculation within each washer and between the series of washers. Since the wastewater is rather strong and contains high amounts of dissolved solids, chlorinated lignins and tannins, BOD, and color; it is rarely useful for pulping or paper making purposes.

White water from paper machine operations can be considered of relatively high quality and suitable for reuse in several processes. After reclaiming fiber and filler materials from these waters in savealls, white water can be reused within the paper machine; or for other processes, such as stock preparation, bleaching, pulp washing, and wood preparations. Currently, many mills reuse white water only in the stock preparation and paper machine operations, while the excess white water is wasted to the sewer. Reuse of white water for bleaching and pulping processes should result in a significant reduction in overall wasteloads and wastewater quantity from an integrated pulp and paper mill.

Wastewater Treatment Practices

General

In this study, wastewater treatment is being defined as including all processes that are implemented outside the mill (paper or integrated pulp and paper) proper, and those facilities specifically provided to treat all wastewaters that are to be discharged, stored for discharge, prepared for disposal, or partially reused. For this purpose, the pollution abatement facilities are not considered an integral part of the mill's recovery practices. However, it must be noted that treated wastewater can be returned to the mill for use when the water supply is critical or when this practice offsets some of the treatment costs.

Wastewater treatment practices can be divided into four functional groups; pretreatment, primary treatment, secondary treatment, and tertiary treatment. Other practices that are related to treatment and waste disposal include "strong" waste digester liquor and pulp wash water handling and disposal, sludge handling and disposal, and by-product production. In the following discussions, the treatment practices will be discussed in the order mentioned and will include the various specific types of treatment processes and equipment used in each waste removal method. These discussions and related tables and drawings will be structured to follow step-by-step flow patterns through typical wastewater treatment facilities. However, the arrangement of treatment processes or equipment can vary according to the characteristics of the waste and the degree of treatment required for any given mill.

Waste Removal Efficiencies for the Base Year

As wastewater treatment methods are being described in the following sections of this report, the normal waste removal efficiencies for these methods, as utilized by the industry in 1963, can be ascertained from Table No. 6. However, pretreatment methods, primarily in the removal of grit and debris from the wastewaters, are not listed in this table because of insufficient data on which to base or determine the amount of grit and debris discharged to the mill sewers. The quantity of grit and debris entering a mill sewer is a function of the mill's specific location, maintenance operations, housekeeping practices and wastewater collection system.

The ranges shown in Table No. 6 for removal efficiencies are considered typical of normal wastewater treatment practices in the year 1963. However, the literature reports that mills located where reasonably priced land was available tended to have higher removal efficiencies than the removal levels presented in the table. Because these treatment facilities were designed (without land limitations) to allow for longer wastewater retention than is normally possible, a greater degree of removal is attainable.

Since only limited treatment plant information and laboratory data were available, COD and color removal data were estimated. Until recently, these data were not collected and recorded as part of normal treatment plant operations.

Table 6

Normal Waste Removal Efficiencies for 1963

Removal Method	Removal Efficiency in Percent of Gross Waste Load to Each Removal Method			
	Suspended Solids	BOD_5	COD	Color[1]
Primary Treatment				
Sedimentation Basin	50-90	10-40	10-30	-
Gravity Clarifier[2]	60-90	10-40	10-30	0-10
Dissolved Air Flotation	70-95	20-50	10-40	-
Secondary Treatment				
Oxidation Pond	0-90	30-50	-	0-10
Trickling Filter	-	30-70	20-50	0-15
Aerated Lagoon	-	40-85	30-60	0-10
Activated Sludge	-	75-95	30-70	10-30
Irrigation	-	60-95	-	-
Sedimentation Basin[3]	60-95	-	-	-
Secondary Clarifier[3]	70-98	-	-	-

[1] "True" color (dissolved).

[2] With or without chemical addition and/or flocculation.

[3] As used to remove biological solids in secondary treatment.

Tertiary treatment practices include "polishing" or removal of specific pollutants; i.e., color and dissolved solids. However, these data covering these practices are not included since they were not utilized in 1963.

Sequence and Alternatives in Mill Wastewater Treatment

Wastewater collection systems in pulp and paper mills vary, but one of the most common practices is to discharge wastewaters to separate sewers according to the wastewaters' strength and characteristics. The various mill wastewater sources shown in Drawing No. B-5 are normally combined into three separate sewer flows by the time they reach the treatment site. (Note: Drawing No. B-5 and all subsequent discussions exclude sanitary and cooling waters.)

All mill wastewaters could possibly be combined and conveyed to the treatment site in one trunk sewer. However, quite often ash wastewater (if coal is used to generate steam), boiler blowdown, and other operational wastewaters containing inorganic chemical wastes are separated from process wastewaters.

Another collection system, which is normally segregated, transports acid wastewaters in acid-proof sewers from bleaching sequences and miscellaneous acid processes, such as chlorine dioxide production, digester cleaning, and tall oil production. Digester pulping liquor and pulp washing wastewater flows are shown on Drawing No. B-5 to indicate that frequently small amounts of this material reach the process sewer because of spills, leaks, or bleeding from the pulp production area of an integrated mill. The digester liquor produced during sulfite pulping is sewered, since recovery is not often practiced. However, in most instances, the handling of the bulk of liquor and washer water is a function of in-plant recovery and control and will only be discussed briefly under wastewater treatment.

The major pollutants of concern to the paper industry are temperature, BOD, COD, color, dissolved solids, suspended solids, and bacteria (coliform). Unfortunately, there is no single treatment process that can effectively remove all these contaminants, and a treatment sequence is necessary. Treatment processes can be grouped into four major categories.

1. Pretreatment facilities are designed to remove grit and coarse material, to neutralize acid or alkaline wastes, to equalize the quantity and quality of waste characteristics, and sometimes to reduce the temperature or to eliminate the odor problem by the mixing of bleachery and digester liquor wastes.

2. Primary treatment is designed to remove the suspended solids and some coarse organic material.

3. Secondary treatment is designed primarily to remove BOD and a portion of the COD.

4. Color, dissolved solids, and coliform are not easily removed by the three previous methods and for effective removal require tertiary treatment. To date, no tertiary treatment processes are being applied in the paper and pulp industry.

Pretreatment

In the context of wastewater treatment, pretreatment includes the initial operations that prepare or condition the wastewater prior to primary clarification. Wastewaters discharged to pretreatment facilities from mill sewers can be either combined mill effluent or segregated wastewaters. Since many collection and combination systems are used in the industry today, only pretreatment of the main mill flow will be discussed. Drawing No. B-5 can be used to study several of the many wastewater combination systems possible, noting that the smaller wastewater flows (such as ash and acid sewer discharges) are often combined with the main mill flow just prior to entering the pretreatment facility. Although they are not considered a part of the treatment facility, pumping stations and sewer extensions that are needed to conduct wastewaters to the treatment plant site are an integral part of the design, operation, and costs of pollution abatement facilities.

The most common pretreatment methods employed are grit and debris removal, and wastewater screening. Inorganic ash, grit from the wood preparation process, and runoff materials (sand and gravel) must be removed from the wastewaters to prevent abrasion of pumping, piping, and solids dewatering equipment. The grit chamber is a gravity settling tank that can be either manually cleaned periodically or continuously cleaned by mechanical removal equipment. By maintaining a desired wastewater flow velocity, these facilities are designed to remove approximately 70 to 80 percent of the grit and to minimize the amount of organic material and fiber removed with the grit. Limited data indicate that grit in the main sewer of integrated mills with a combined sewer system may roughly total 0.25 to 0.5 cubic yard per mgd of wastewater flow during dry weather conditions.

Bar screens, which can be manually or mechanically cleaned, are commonly used to remove debris from the wastewater stream. Designs for new facilities tend to incorporate mechanically cleaned units rather than the manually cleaned units in order to reduce maintenance costs. A bar screen is composed of vertical bar "racks" and is designed to prevent clogging of overflow weirs and primary clarifier sludge withdrawal lines. To accomplish this function, the normal spacing between bars is 3/4 to 1-1/2 inches.

Fine screens are not as common in wastewater pretreatment as other types of screens used to remove grit and debris. The need for fine screening is a function of an individual mill's operation and the design of waste solids handling and dewatering facilities. The screens, with openings of 3/8 to 3/4 inch, are normally used to remove knots, waste broke, bark, other fibrous and wood-type materials discharged to mill sewers which can pass through the bar screens. Normally, this equipment is sized to remove the smallest material that will cause clogging of pumps, pipes and other downstream facilities. The screening facilities can be of various types and include the following: 1) self-cleaning rotating discs that remove solids from the wastewater as it flows horizontally by gravity through the facility; 2) vibrating screens that remove and clean the material by back-and-forth, or bouncing-type motion, as the wastewater passes through the screen; 3) traveling screens of conveyer belt-type design that normally permit gravity flow of the wastewater through the screening material; 4) drum screens that remove the solids on the inside of the drum as the flow passes through the screen.

A pretreatment process that has become important in recent years is the neutralization of mill wastewaters. Not only does the pH of the wastewater affect conditions in the receiving stream, but extreme pH conditions can cause corrosion of mechanical treatment equipment or spalling of concrete structures as well as adversely affecting secondary treatment. Wastewater pH should be in the range of 6.0 to 9.0 to prevent damage to primary treatment facilities, and normally, between 6.5 and 8.5 to prevent upsets in secondary biological treatment systems. The selection of a neutralization method is a function of the separation of process wastewater sewers in the mill, since wastewater streams vary in pH, alkalinity, and acidity. In the example of sewer segregation previously mentioned, the acid bleach plant effluent, chlorine, and related chemical production wastewaters contain large concentrations of hydrochloric, sulfuric, and other acids whose pH values vary from 1.5 to 2.5. Ash wastewaters discharged from power plant and lime recovery operations contain large amounts of inorganic, highly alkaline solids. Wastewaters coming from the pulping operations can vary from acidic to highly alkaline conditions depending upon the pulp process being utilized. Wastewater from Kraft pulping is alkaline; while from sulfite pulping, it is generally acidic. Caustic digestion and washing waters and caustic extraction wastes from bleach plant operations tend to give the "main mill wastewater" (pulping and white water wastes) a wide pH range; from a low of 3.5 to as high as 11 or 12.

Therefore, the need for and degree of neutralization required for mill wastewaters depends primarily on the type of pulping process, and whether the wastewaters are collected and sewered to the waste treatment site separately. Mill experience has shown that separately collected wastewaters can be combined or added in a manner to offset extreme alkaline and acidic conditions of an individual wastewater stream in a Kraft mill. However, if the wastewater stream to be neutralized is the total effluent from the mill, extreme fluctuations in the pH and alkalinity-acidity can be expected. Therefore, caustic and acid chemicals used to neutralize this wastewater must be added in the pretreatment step to prevent corrosion in piping and concrete facilities and to protect secondary biological systems from extreme pH fluctuations. Because of the wide variations which can occur, facilities should be partially or totally automated to prevent high operating costs and frequent biological upsets.

An additional process that will be considered as pretreatment (although it can be inserted at several points in the wastewater treatment scheme) is wastewater cooling. As previously mentioned in this report, paper mill and integrated pulp and paper mill wastewater temperatures are high as compared to ambient temperatures of receiving surface waters. Of primary concern in wastewater treatment is the effect of the wastewater temperature on secondary treatment biological processes. Temperatures of greater than 100°F have caused reduced efficiency in the biological process. Cooling of the wastewaters can be accomplished by several methods; cooling towers, spray ponds, cascade channels, and detention ponds. The use of cooling towers and cascade channels may aggravate the foaming problem that accompanies pulp and paper mill wastewater treatment. Cold water sprays and antifoam agents are generally used to control foaming. However, large quantities of fresh, cold water are not always available at mill sites and the addition of antifoam agents, if effective, is often very expensive.

Discharging wastewaters to a cooling pond is effective if time and space are available. Cooling ponds can be used in conjunction with another pretreatment method, equalization. Whether equalization is used before primary treatment or between primary and secondary treatment, it involves the combination and retention of the wastewaters to minimize fluctuations of pH, flow, temperature, and other characteristics of the wastewater stream. Equalization is generally used after primary treatment so that solids do not settle out in the wastewater holding facility. However, if equalization is used prior to primary treatment, mechanical mixing of the wastewater is necessary to prevent sediment build-up in the holding basin or tank.

Primary Treatment

The next major treatment requirements is the removal of suspended solids. The concentration of suspended solids in the wastewater depends upon many conditions and operations within the mill proper. Large quantities of collodial materials and other dispersant-type chemicals in mill wastewaters may tend to inhibit gravity settling of suspended solids during quiescent conditions, as will extreme differentials between ambient air and wastewater temperatures. In the former case, flocculation of the wastewater can be used as a conditioning step for primary clarification. Flocculation, with or without the addition of flocculating chemicals, such as alum, ferric chloride, or polyelectrolytes, can be done externally or as an integral part of the primary clarifier. Chemical addition facilities should be designed to avoid chemical additions, which could result in increased sludge production.

The flocculated wastewater, or unconditioned wastewater, can be clarified by gravity settling or dissolved air flotation. Generally suspended solids from pulp and paper mills are susceptible to gravity settling; therefore, circular or rectangular gravity clarifiers are commonly used. The design range for hydraulic loadings in primary clarifiers is from 600 to 1000 gallons per square foot of surface area per day, with 800 being a common value. Settling lagoons have also been used for gravity clarification. Dissolved air flotation has been used as an effective treatment method for the removal of suspended solids in certain mills. An example of air flotation, applicable in the pulp and paper industry, is the removal of very fine fibers and solids found in the effluent from sulfite mills. Quite often, dissolved air flotation is used to recover pulp materials that can be reused in the mill. For this process to function properly, it sometimes is necessary to add sweetener stock (pulp) to aid the recovery operation.

The BOD that is removed in primary treatment is related to organic and fibrous materials that settle out of the wastewater. True (dissolved) color is not removed by primary clarification unless flocculation has caused adsorption, whereby the color adsorbed on floc particles would settle out of the wastewater. The true color of lignin and tannin origin is not affected or removed by primary treatment.

Equalization facilities are often provided between primary and secondary treatment facilities to control variations in mill wastewater flows and characteristics. Wastewater surges, high wastewater temperatures, and extreme pH conditions can cause degradation of biological processes used in secondary treatment. The retention times in equalization facilities can vary from several hours to several days, depending on the type of fluctuations to be dampened and the resistance or buffering capacity of the biological system.

Secondary Treatment

The primary purpose of secondary treatment is to remove soluble BOD, using biological treatment processes. Prior to biological treatment, certain nutrients that are vital to the existence of a balanced biological community and normal life-cycle activity must be added to the wastewaters. The essential nutrients are nitrogen and phosphorus, which are generally added in the form of ammonia and phosphoric acid. The dosage required is governed by the concentration of these chemicals present and by the organic (BOD) strength of the raw wastewater. Mills using large amounts of alum require larger dosages of phosphoric acid because of the bonding and removal of phosphorus by the alum molecule. Ammonia is added to the wastewater either as a gas or a liquid, depending upon which is available and the quantities required. Under normal conditions, one part of phosphorus and five parts of nitrogen are needed per one hundred parts of BOD to be removed in secondary treatment. The nutrient addition and control have a major effect on the operation of a biological system. Nutrient starvation can result in filamentous biological growth, lower removal efficiencies and poor settling characteristics in the biological sludge. This type of operational problem is common in the treatment of pulp and paper mills' wastewaters when attempting to obtain a high degree of BOD removal.

The conventional activated sludge process, as a biological treatment system, has been used in the paper industry to attain a high rate and degree of BOD removal. Comparing the activated sludge process with other biological systems, the major difference lies in the quantity of the acclimated microorganism (sludge, brought into contact with the wastewaters. This factor greatly influences the removal and stabilization rate of the soluble BOD materials. To function properly, the activated sludge process requires:

1. Defined and/or controlled BOD loadings.

2. Sufficient oxygen supply for oxidation and synthesis reactions to occur.

3. Adequate time to complete the oxidation and synthesis reactions.

The activated sludge process is implemented by contacting the mill's wastewaters with an acclimated biological population in the presence of dissolved oxygen. The biological population feeds on the organic materials present; thus removing them from the wastewaters. Effective removal and stabilization of BOD means that the biological community is healthy, and will result in the production of additional biological organisms. To sustain the process, the biological mass is separated from the wastewaters by gravity settling and is returned to the beginning of the process. Since additional biological organisms are generated, it becomes necessary to waste a portion of these to maintain an optimum environmental condition.

At times, the biological reactions occurring within the activated sludge process readily remove the BOD-causing material from solution but additional time may be needed to complete the stabilization reactions. To take advantage of this phenomena, the contact-stabilization modification of the activated sludge process was developed. Basically, the process consists of contacting acclimated biological organisms with the wastewater for a sufficient time to accomplish the desired removal of BOD; with return of the settled organisms to the separate aerated stabilization basin where the synthesis reactions are completed. The stabilized organisms are then recontacted with the wastewater. The advantage of the contact-stabilization process is that less tank volume is required since stabilization is accomplished at much higher organism concentrations. Also, since the mass of biological organisms are outside of the main wastewater stream and if toxic or other upset conditions are encountered, the system can usually be returned to its original condition in a shorter period than with the conventional process.

In treating wastewaters from paper mills, both the conventional activated sludge process and the contact-stabilization modification process have been used successfully.

The conventional activated sludge process is particularly amenable to wastewaters from sulfite mills. Past experience with this wastewater indicated that oxygen transfer to the biological process was a problem, and without the required amount of oxygen, a healthy system cannot be maintained. Technological advances in mechanical aeration equipment design in the past few years have overcome this problem. Eighty-five (85) percent BOD removals are attainable with a detention time of four to six hours with a mixed liquor suspended solids concentration of 2000 to 3500 mg/L. This process produces approximately one-half to one pound of excess biological organisms per pound of BOD removed, and requires one to two pounds of oxygen per pound of BOD removed.

The contact-stabilization modification of the activated sludge process is particularly applicable to integrated Kraft mill effluents. BOD removals of 85 percent are readily attainable with two to three hours contact time and two to three hours stabilization time when using a mixed liquor suspended solids concentration of 2000 to 3000 mg/L in the contact phase. Oxygen requirements and sludge production are about the same as in a conventional system when treating wastewaters from an integrated sulfite mill.

The gravity settling of the biological organisms occurs in units commonly called secondary clarifiers. Clarifiers for biological plants are designed on the basis of overflow rate; and for paper mills, the design rate is generally 600 to 800 gallons per day per square foot based on forward flow. Problems can occur in biological treatment plants attaining a high degree of BOD removal as a result of light dispersed biological growths not being removed when using conventional clarifier arrangements. Recently the peripheral-feed, suction sludge draw-off clarifier has found increased usage in this application. Up to 98 percent of the solids, depending on the influent concentration, can be removed from the wastewater. Effluent concentration of from 50 to 100 mg/L suspended solids are common.

Trickling filters also have been applied in the treatment of pulp and paper mill wastewaters. Biological growths are attached to the synthetic or rock media of the filter. This biological growth removes the waste organics from the wastewater as the wastewaters trickle through the media. The advent of synthetic media in recent years has made this approach more economically attractive, although they still have the limitation of being unable to achieve as high a BOD removal efficiency as economically as activated sludge for pulp and paper wastewaters. In treating this type of wastewater, filters have a tendency to clog with slimy materials and cannot buffer fluctuations in the wastewater characteristics to the same degree attainable with the activated sludge process. Recent interest has developed in the possibility of combining the activated sludge and trickling filter approaches to obtain greater efficiency in treating pulp and paper mill wastewaters. In these applications, the plastic media filter is utilized for wastewater cooling and as a roughing filter at loads of approximately 100 to 700 pounds of BOD per day per 1000 cubic feet of media. This approach has been economically and technically feasible for some applications.

Another biological treatment method is the use of lagoons or stabilization ponds where low concentrations of biological solids are maintained to remove BOD. Frequently used is the aerated lagoon, which is capable of removing from 40 to 75 percent of the BOD present in mill wastewaters. Offsetting the space requirements and other physical limitations of the approach are the recent improvements in floating-type aerator equipment and synthetic basin liners. Presently, this type of biological treatment does not usually provide final clarification before the treated wastewaters are discharged to receiving streams. Typical design conditions for an aerated lagoon are from one to two acres of lagoon per mgd of wastewater flow, or roughly 10 pounds of BOD applied per 1000 cubic feet of lagoon volume per day.

The stabilization basin, shown on Drawing No. B-6, is a form of aerated lagoon which was used prior to the development of surface aerators. Although this secondary treatment method did not normally receive formal engineering design, if affected a BOD removal equivalent to that attained with a well-designed oxidation pond. However, using air diffusers as a source of oxygen, these facilities could be deeper than oxidation ponds.

Oxidation ponds (i.e., stabilization ponds without supplemental oxygen) have limited application in the pulp and paper industry, since wastewater color is usually higher than that of sanitary waste and, consequently, reduces or prohibits the production of the algae normally present in sewage oxidation ponds. However, for mills located in the south, where climatic conditions are appropriate for photosynthetic activity throughout the year and large land area is often available, this method is reasonably effective. Design of industrial oxidation ponds is similar to sewage treatment applications; the pond must be about five feet deep and should receive a loading of about 50 pounds of BOD per acre per day. Typical paper industry practice provides 40 to 50 acres of pond area per mgd of mill wastewater.

Irrigation disposal of pulp and paper mill wastewaters is also a form of secondary treatment. Operational problems, such as runoff, stream pollution, and freezing of the wastewaters during winter conditions limit the applicability of this approach. When designed properly, this method can be used seasonably in forested areas; recent publications have shown that better than 60 percent of the BOD can be removed before the wastewater reaches groundwater levels. Land application levels for the paper industry vary from 10,000 to 100,000 gallons per acre per day. Studies of this practice have indicated the loading for the industrys' wastewaters should be less than 200 pounds of BOD per acre per day.

Tertiary Treatment

Tertiary treatment is used to obtain additional removals or "polishing" of wastewaters before discharge to receiving waters. The major pollutants of concern to the paper industry are temperature, BOD, COD, color, dissolved solids, suspended solids, and bacteria (coliform). Data show that previously described treatment methods have been effective in the removal of color, dissolved solids, or coliform.

Pulp and paper manufacturing operations return to the natural environment certain elements typical of the natural resource (timber) used by this industry. From a water pollution standpoint, two important elements are lignins and bacteria found in the wood used to make pulp. The industry discharges lignins in the form of dissolved color in the mill effluent and bacteria as concentrated bacteriological communities of nonpathogenic nature. Since both elements are concentrated in the mill wastewaters and are difficult to control in the mill or to remove by the present wastewater treatment practices, they pose an economic and technical problem to the industry. To date, the paper industry has not applied tertiary treatment practices on a plant scale to remove color and bacteria from mill wastewaters. Several basic reasons have limited its application: 1) advanced tertiary treatment has not been required of industry in general; and 2) although newer tertiary treatment methods are technically feasible, these practices are economically practical.

Generally, tertiary treatment steps have been adopted in the additional removal of BOD and COD from industrial wastewaters. The most widely used facility for tertiary treatment is the holding pond. The storage of secondary-treated wastewater before discharge to the receiving stream can be utilized to attain additional BOD and COD removal by limited biological activity, and the removal of solids by extended detention and bacterial flocculation. Aerobic conditions are needed to permit additional removal without nuisance and to provide a positive dissolved oxygen content in the discharge to receiving waters. Data are not available from the paper industry to evaluate the extent of the use of this practice nor its effectiveness as a pollution abatement method.

Other methods available to the paper industry for supplemental organic removal are biological filtration and irrigation.

If bacteriological criteria are part of future effluent discharge requirements for the paper industry, it will be necessary to use some form of bacterial destruction method; chlorination being the most frequent choice. However, since the chlorine demand of biologically treated pulp and paper mill effluents can be as high as 60 to 100 mg/L, this can be a very expensive operation. The use of ozone has not been investigated by the industry, but this approach provides an additional benefit in that partial color removal can also be achieved. To date, in the pulp and paper industry, neither chlorination nor ozonation have been practical for bacterial removal because of the high chemical demands and relatively high wastewater flows. It should be noted that recent regulatory action has been toward the separate determination of total and fecal coliform concentrations when determining bacterial pollution. Mills collecting sanitary sewage separately should have minimum concentrations of fecal bacteria in process wastewaters unless these bacteria have multiplied in sewers and treatment facilities.

Significant color removal has been achieved in the laboratory by several methods; activated carbon adsorption, mass lime and other chemical adsorption processes, and foam separation. To date, these methods have not been evaluated in full-scale plants treating pulp and paper mill wastewaters. Indications are that up to 90 percent of "true" color can be removed from mill wastewater. However, to date it has not been considered economically feasible to apply these methods to the treatment of total mill wastewater flows.

Data from laboratory investigations and full-scale operations indicate that the degree of color removal accomplished by a given biological treatment system (activated sludge) appears to be a fixed amount, typical of adsorption phenomena. Activated sludge facilities can be expected to remove approximately 10 to 15 percent of the color in a wastewater from a Kraft mill, which includes a bleaching operation (the principal source of color in Kraft mills). Higher color removal efficiencies have been observed for secondary treatment facilities when secondary influent color concentrations have been reduced by in-plant measures. Such observations reinforce the concept that in-plant treatment is most likely a more effective (and economical) method of color removal. Studies on the massive lime treatment method on caustic bleaching wastes have demonstrated that as much as 90 percent reduction of the color can be expected from the use of this technique in full-scale facilities. This process combines three basic steps:

1. Adsorption and chemical reaction on the surface of the lime.

2. Precipitation and dewatering of the lime solids.

3. Recausticizing of the lime.

In the present status of technology of color removal, this method appears to be the most feasible for removal of pulp mill effluent color.

Inorganic solids removal can be achieved by several tertiary treatment methods. However, very little data are available to evaluate the effect and feasibility of such methods, which include electrodialysis, reverse osmosis, and ion exchange. Combinations of methods, such as carbon adsorption followed by electrodialysis, have been proposed for wastewater renovation. Although treatment costs are increased, a portion of the costs of removing these inorganic solids is offset by the benefits derived from water reuse. This approach cannot be considered generally applicable where an industrial water supply is readily available at a reasonable cost.

Sludge Disposal

The handling, dewatering, and disposal of primary and secondary sludges are important factors in the design and operation of wastewater treatment facilities in the pulp and paper industry. Although sludge can be withdrawn from the primary clarifiers at solids concentrations up to approximately 10 percent, it is usually pumped from the sludge storage zone in the primary clarifiers at from 3 to 6 percent solids. This is because pumpage and pipe clogging problems are encountered at the higher densities. The clarifier underflow is dewatered in various ways, depending on the type and quantity of solids discharged from the individual mills' operations. Normally, primary sludge does not require separate thickening prior to dewatering.

In discussing dewatering equipment, it should be noted that the primary sludge can be mixed with secondary sludge (normally withdrawn from secondary clarifiers at about 1 percent solids concentration) or the sludges can be handled and dewatered separately. At best, secondary sludge with solids that are 60 to 90 percent volatile will gravity thicken to no more than 2.5 to 3 percent solids concentration at loadings of 10 to 20 pounds/sq. ft. If this material is not readily susceptible to gravity thickening, it can be mixed and dewatered with primary sludge or thickened by dissolved air flotation or centrifugation. Dissolved air flotation is capable of thickening activated sludge to about 4 to 5 percent, while centrifugation is capable of obtaining 5 to 8 percent solids.

If these sludges (handled separately or combined) can be withdrawn from clarifiers at, or thickened to, the necessary concentrations (about three to five percent solids by weight), several dewatering methods are available. The most widely used method to date has been vacuum filtration. Conditioning chemicals are often required in this operation. Filter cake concentrations of from 15 to 25 percent solids can be achieved.

Recent studies and operational data have shown that centrifugation is very effective in dewatering pulp and paper mill sludges. Primary sludge alone can be readily dewatered on a solid-bowl centrifuge to between 20 and 35 percent solids concentrations. Combined sludges, at feed solids concentration of 5 percent or greater, can be dewatered on the solid-bowl centrifuge to 15 to 25 percent solids concentration; the performance level depending upon the fiber content of the sludge. Centrifugation of secondary sludge alone usually requires chemical conditioning, commonly in the form of polyelectrolytes. Thus treated, it can be dewatered to 12 to 20 percent solids.

Other types of dewatering equipment include sludge presses, drying beds, and sludge lagoons. The selection of dewatering equipment depends on the sludge characteristics, the amount of land available, ultimate disposal considerations, the isolation of wastewater treatment and sludge disposal site, and proportion of primary and secondary sludges. Waste secondary sludge can cause problems in lagooning and landfill operations because of the high organic content. A method utilized by other industries and domestic sewage treatment plants to stabilize sludge for subsequent disposal, but which has not been widely adopted in the paper industry, is the aerobic digester. An additional function of this process is reduction of the quantity of organic material in the sludge. Aerobic digestion is accomplished in a tank that provides 10 to 20 days detention, during which time the organic content of the sludge is reduced by 30 to 60 percent and is adequately stabilized to permit nuisance-free disposal.

Ultimate disposal of waste sludges is a "solid waste" problem. In the past, these materials have generally been disposed of by landfilling and lagooning together with other mill wastes products, such as bark, ash, grit and debris. However, with increasing land costs, decreasing land availability and more stringent regulations concerning solid waste disposal; recent solid waste systems have included incineration of primary and secondary sludges. The following types of incinerators can be used to burn sludge resulting from the industry's wastewater treatment operations:

1. Multiple Hearth Furnace - commonly used for waste incineration and steam production.

2. C. E. Raymond System - utilizes recycle of dried sludge and furnace gases to reduce moisture content of sludge before incineration.

3. Rotary Kiln - widely used in the paper industry for recalcination of lime in pulping operations.

4. Atomized Suspension Technique (AST) System - or Thermosonic Reactor System, consists of a cyclone evaporator and reactor for high temperature oxidation.

5. Zimmerman Process - a high pressure wet combustion process.

6. Bark Burners and Mill Boiler Furnaces.

7. Fluidized Bed Systems - for liquor recovery, sludge destruction and bark burning, and utilizing an air or gas flow suspended bed of sand or generated particles as the incineration area.

Optimum incineration of primary and secondary sludges requires that this material be at least 40 to 50 percent solids concentration to reduce the need for supplemental fuel.

Mechanical presses have been evaluated to further dewater sludges, after vacuum filtration or centrifugation, but not with consistent results. Successful dewatering by this method is dependent upon a high fiber content. Dryers utilizing incinerator gases, heat exchangers, and cyclone evaporators are also effective as a further sludge drying operation.

Strong Wastes Disposal

Although digester liquor can be recovered, there are several disposal methods which can be considered as waste removal practices. Of recent interest has been the deep well disposal of liquor and pulp washer water. The effects on groundwater quality depend on the geological formations at the mill location and the amount of waste discharged to the well. Generally this form of treatment is not considered to last indefinitely because of clogging in the injection formation. Another disposal method is the dilution of spent liquors for land application; basically, the factors defining irrigation disposal of process wastewaters can be applied to this practice. However, runoff from such operations can cause significant damage to receiving stream conditions because BOD and solids concentrations in the liquor and washer water are greater than those contained in other process wastewaters.

Wastewater Treatment By-Products

Presently the sludges resulting from mill wastewater treatment are not used for production of marketable by-products. The uses of dewatered primary sludge for sanitary landfill and dewatered secondary sludge as a soil conditioner are not considered by-product areas since this material is normally given away as a means of minimizing solid waste disposal efforts and expenses.

Areas of future by-product development to offset treatment costs are: 1) fiber recovery from primary sludge for use in the building materials industry; 2) drying activated sludge for use as a fuel supplement; and 3) processing activated sludge as an animal food supplement or commercial fertilizer.

Rate of Adoption of Wastewater Treatment Practices

The portions of the industry that have adopted or will adopt the various wastewater treatment practices for the years 1950, 1963, 1967, 1972, and 1977 are listed in Table No. 7. Drawing Nos. B-6 through B-8 show the practices and alternative methods of treatment that are associated with older, present, and newer wastewater treatment technologies in the paper industry. To date, a comprehensive survey of treatment practices in the paper industry has not been completed. Most of the data presented in Table No. 7 have been extrapolated from information assembled by the National Association of Manufacturers and the National Council for Stream Improvement as well as from specific pieces of data available in the literature. Particularly in regard to smaller equipment, data reflect estimates based on information from the literature and industrial sources.

Pretreatment equipment, although not as mechanically sophisticated and automated as present units, was utilized in conjunction with primary treatment prior to 1950. Presently, about 60 percent of the industry provides grit and debris removal (roughly one half of this is mechanically cleaned equipment), and by 1977 nearly all plants will provide debris and grit removal and neutralization.

Table 7

Rate of Adoption of Waste Treatment Practices[1]

Practice (or Equipment)	Percent of Industry Employing Practice				
	1950	1963	1967	1972	1977
Pretreatment					
Grit Removal	20	40	60	75	90
Bar Screen	20	40	60	75	90
Fine Screen	-[2]	-	-	-	-
Equilization	10	20	25	30	40
Neutralization	10	25	40	60	80
Cooling	-	-	-	-	-
Primary Treatment					
Sedimentation Basin	10	5	5	<5	<5
Flocculation	<5	<5	5	10	15
Gravity Clarifier	25	60	70	85	90
Dissolved Air Flotation	-	-	-	-	-
Secondary Treatment					
Nutrient Addition	pilot	10	20	50	80
Oxidation Pond	10	15	20	20	20
Trickling Filter	pilot	<5	<5	5	<10
Aerated Lagoon	none	<5	5	20	25
Activated Sludge	pilot	<5	5	25	30
Irrigation	none	<5	<5	5	5
Sedimentation Basin	none	<5	5	10	10
Secondary Clarifier	none	5	10	40	50
Tertiary Treatment					
Supplemental Organic Removal	none	none	pilot	-	-
Color Removal	none	none	pilot	-	-
Inorganic Removal	none	none	pilot	-	-
Bacterial Removal	none	none	none	-	-
Deep Well Disposal	none	<1	<1	<5	<5
Sludge Handling and Disposal					
Thickening					
Gravity Thickener	-	-	-	25	40
Dissolved Air Flotation	-	-	-	-	-
Centrifugation	none	none	<5	10	15
Digestion[3]	-	-	-	-	-
Dewatering					
Vacuum Filtration	5	20	25	35	40
Centrifugation	none	<5	5	20	40
Pressing	<5	<5	5	5	5
Sand Bed Drainage	-	-	-	-	-
Disposal					
Lagooning and Landfilling	30	60	60	50	30
Incineration	<5	5	10	25	40
By-Product	-	-	-	5	10

[1] Including related practices such as sludge disposal.
[2] No data presented.
[3] Primarily aerobic digestion of biological sludge.

Flocculation will not significantly increase as a primary treatment practice because of the added emphasis being placed on in-plant measures to reduce the loss of colloidal chemicals and paper additives. Essentially all mills not discharging to municipal sewers will provide treatment (largely as circular clarifiers) by 1977. Due to land requirements, sludge handling difficulties, and problems in maintaining consistent operation; settling lagoons will not be an important factor in future primary solids removal practices.

Since most mill wastewaters do not contain sufficient amounts of nutrients required for biological treatment (phosphorus and nitrogen), secondary treatment facilities will incorporate some form of nutrient storage and addition facilities. Of the five secondary treatment methods listed on Table No. 8, the activated sludge process will be the most widely used method in 1977. This prediction is based on the high degree of treatment and operational control that will be needed to meet effluent criteria 10 to 15 years from now. The aerated lagoon approach can compete economically with the activated sludge process in rural areas, but frequently the land requirements are prohibitive. The 1950, 1963, and 1967 percentages for mills using oxidation ponds include most effluent storage ponds, although many of these were not designed as treatment ponds. However, the data for 1972 and 1977 reflect the percentage which will be using ponds as a treatment method.

Even though recent studies have indicated that tertiary treatment methods are technically feasible for color, bacterial, BOD, COD, and inorganic removals, such methods are not being applied at this time. Consequently, it is difficult to define their rate of adoption based on past applications.

Sludge thickening by gravity has been successfully used on primary sludges and appears to be equally applicable to combined primary-secondary sludge thickening. Centrifuges are very effective in thickening sludge, especially secondary sludges that are difficult to dewater by other methods. Although commonly a more expensive method than vacuum filtration, centrifugation has recently gained popularity in dewatering applications because of ease and flexibility of operation and low space requirements. It is believed that this approach will close the gap in the portion of the industry employing centrifuges versus those using vacuum filtration by 1977.

Ultimately, most mill wastewater treatment sludges generated will be incinerated. The potential for by-product development and marketing will expand in the future but not to a degree sufficient to offset the need for complete incineration. In rural areas, landfilling and lagooning are, and will continue to be, common practices controlled by two factors, availability of land and regulatory actions regarding proper sanitary disposal.

Wastewater Discharge to Municipal Sewers

There are no data available to serve as a basis for estimating the portion of the pulp and paper industry which was discharging its wastewaters to municipal sewers in 1950. However, a rough approximation is that between 5 and 10 percent of the industry were utilizing this method. The adoption of this practice depended upon, among other things, the mills proximity to a sewerage system and the willingness and ability of municipalities to accept these wastewaters. In 1950, the effects of pulp and paper mill wastewaters on treatment processes in sewage treatment plants were not well defined, nor were criteria developed upon which to assess the acceptability of paper mill wastewaters for joint treatment with municipal sewage.

Presently (1963-1967), approximately 10 to 15 percent of the pulp and paper industry discharge their effluents into municipal sewers. The characteristics of pulp and paper mill wastewaters, as well as those of other industrial wastes, are now better understood so that the effects of such wastewaters on the sewage treatment processes and the factors governing their acceptability for combined treatment with sewage can be defined and applied.

A very important factor in considering the combined treatment of pulp and paper mill wastewater with sewage is the relative flow and organic loading between the two types of wastewater. Where the flow or loading of the pulp and paper mill wastewater is a small portion of the total flow to a municipal system (i.e., less than 10 percent), the industrial wastewater would not be expected to have a significant effect on the performance of primary and secondary sewage treatment facilities. The reference here is to general mill effluent, not to strong liquors and other concentrated wastewaters. Where the industrial wastewater would represent a significant portion of the total wastewater flow, specific account must be taken of the treatment characteristics of the industrial wastewater in the design or prediction of performance of the combined wastewater treatment facilities. Combined systems have been designed and are operating where the principal wastewater, in terms of hydraulic or organic loading, is an industrial waste; including pulp and paper mill wastewaters. In those cases, the treatment facility has been designed, as it must be, to meet the requirements of treating the industrial wastewater. Therefore, these treatment facilities can more accurately be described as an industrial waste treatment plant with sewage included.

In considering the combined treatment of pulp and paper mill wastewaters and municipal sewage, several handling and treatment characteristics, peculiar to the industrial wastewaters, must be considered prior to the acceptance of such wastes into an existing municipal system or when providing for such wastewaters in the design of a new combined collection and treatment system. The manner of coping with these problems will vary, depending upon local conditions; whether it is a new or existing system, the relative amounts of each type of waste material, the nature and size of the wastewater collection system, the type of treatment process if an existing plant, etc. Frequently for existing systems, the only means of accomplishing the desired handling and treatment amenability is to require appropriate pretreatment by the mill prior to discharge to the combined system. Some of the characteristics of pulp and paper mill wastewaters requiring special consideration in combined systems are:

1. High temperatures, particularly with regard to their effect on collection systems and on treatment rates.

2. pH of the wastewater; the pulp and paper mill wastewater can vary widely, especially where bleaching operations are involved. Acid wastes from the bleach plant are extremely corrosive. Pretreatment at the mill or protection of at least a portion of the collection system would normally be required.

3. Foaming tendencies; pulp and paper mill effluents, especially those from bleaching operations, frequently create serious foaming problems either in collection systems or at the treatment plant. Again, pretreatment or provision for controlling the problem in the collection and treatment facility are required.

4. Sulfur compounds; the effluents from pulp and paper mills frequently contain relatively high concentrations of sulfur compounds; sulfates, sulfites, sul-

fides, etc. These compounds, if not properly controlled or provided for, can lead to malodors (hydrogen sulfide) in the sewer system or treatment facility, corrosion in the collection system or impaired performance in the treatment plant.

5. Suspended solids; the nature of the suspended solids content of pulp and paper effluents is significantly different from that of municipal sewage and must be considered in the solids handling considerations of combined systems. Colloidal materials, paper additives, clays, and similar materials can hamper settling in primary clarifiers or interfere with anaerobic digestion. Large quantities of fiber and pulp can significantly add to the solids handling load of the combined sludge system and can interfere with digestion. The quantity of excess biological solids generated in the treatment of pulp and paper wastewaters is higher than from the treatment of an equivalent strength sewage.

6. Chlorine demand; the effluent from pulp and paper mills contain materials which have a relatively high chlorine demand. Therefore, for a combined treatment system to maintain a chlorine residual, it may be necessary to use large dosages (60-100 mg/L) as compared to strictly domestic plants (about 10 mg/L).

It can be expected that the number of joint municipal-industrial wastewater treatment systems will increase in the future. The reference here is to plants specifically designed to accommodate either particular industrial wastewaters or a large portion of industrial wastewaters from various industries. The percentage of pulp and paper mill wastewater being treated in such systems is not expected to increase in the same proportion as for industrial wastewaters in general. This is due, principally, to the location of pulp and paper mills in rural areas distant from municipal systems.

By-Product Utilization

From Spent Liquor

Several organic by-products can be recovered from the spent cooking liquor resulting from various types of pulping operations. They include turpentine, tall oil, yeast, alcohols, dimethyl sulfoxide, vanillin, etc.

Turpentine

Digester relief gases from both sulfate (Kraft) and sulfite pulping contain significant quantities of turpentine. The turpentine recovery procedure consists of condensing the cooking relief and decanting the crude oil fractions. The principal components of sulfate turpentine are pinenes; whereas, sulfite turpentine is composed of p-cymene and borneol. Both types can be used as paint thinners and in the manufacturing of insecticides. Yields from either process vary from 1.5 to 4.3 gallons per ton of pulp.

Tall Oil

The black liquor from the digestion of pine contains sodium soap which is derived from the dissolved fatty acids and resin acids present in the wood. After the liquor starts to cool, or its total solids content is increased, the soap rises to the surface, where it can be collected by skimming. This soap contains the crude tall oil, and by various refining operations, the purified tall oil can be obtained. Yields are 180 - 300 lbs/ton of air dried pulp production. Tall oil and its derivatives can be used to make adhesives, emulsions, disinfectants, lubricants, paints and soap.

Yeast

Torula yeast production has the most potential in by-product utilization of the spent sulfite liquor, especially for the calcium-base, sugar-containing spent liquor. The procedure involved is to seed the yeast organisms for fermentation and then pump a continuous supply of sulfite spent liquor to feed the organisms to enhance further growth and multiplication. Additional inorganic nutrients (i.e., nitrogen, phosphates, and potash salts), adequate air supply, and a constant temperature condition (90°F) are required for the optimal production of torula yeast. Since torula yeast contains large amounts of proteins and vitamins, it is used as a food supplement for humans and animals. Data concerning the operation of one mill demonstrate that the waste reduction resulting from yeat production is about 95 percent for total solids, 20 percent for five-day BOD, and 60 percent for total wastewater volume.

Alcohols

Alcohols are attainable by-products in the fermentation of spent sulfite liquor using specific yeast organisms with ethyl alcohol as the first stage product. Ethyl alcohol can be further processed to produce glycols, ethyl acetate, ethylene dichloride and acetaldehyde.

D.M.S.O.

Dimethyl sulfoxide (DMSO) is a valuable compound extracted from liquor dissolved in spent cooking liquor. The complete extraction method includes a series of complicated processes. DMSO can be used as an antiflammatory agent or as a bactericide.

Vanillin

The vanillin is a white, fragrant crystalline substance which can be generated from the calcium-base sulfite spent liquor. By treatment of calcium lignosulphonate, which is a basic component of the liquor, with sodium hydroxide under pressure, the pure vanillin is produced.

Bark By-Products

By-product utilization of bark is currently being studied intensively by the industry. It has been established that bark from particular trees can be used as a source of a salable by-product (tannin from hemlock bark) while many types of bark (redwood, pine, spruce, etc.) can be used directly in the manufacture of roofing felts, thermal insulation materials, and cheap wrapping paper.

Others

Many other by-products can be generated from the sulfite spent liquor. These include emulsions for insecticides, scaling inhibitors for boilers, tanning agents, cement dispersing agents, fertilizers, flotation acids for separation of ores, well-drilling lubricants, extenders in storage batteries, reinforcing agents for rubber, gradients for ceramic industry electroplating, and road binders.

In spite of the numerous fields in which the spent sulfite liquor can be utilized, the amount actually used is very small. The prospect of finding an economical use of waste liquor is questionable at the present technology level, in large part because cheaper and better raw materials for making these products are available.

WASTE REMOVAL ECONOMICS

Replacement Value

The data assembled on pulp and paper mills are representative of the industry based on production data from 40 to 45 percent of the total number of mills. Data and projections of waste removal costs for the total pulp and paper industry have been assembled by the National Association of Manufacturers and the National Council for Stream Improvement. However, replacement costs for specific types of waste removal facilities are not available and are difficult to estimate because the average ages of the mills vary, segments of the various processes have been updated in some instances, and even the average age of the equipment within one mill can vary quite dramatically, making it practically impossible to estimate the average age.

As a general guideline in waste removal equipment replacement costs, the total paper products industry (SIC 26) has spent about $170 million by 1965 for such facilities with an estimated replacement value (in 1966) of $220 million. Based on this information it appears that the replacement costs in 1966 would be about 30 percent more than the invested capital for treatment facilities in 1965 and previous years. The current (1967) capital and operating costs of wastewater treatment facilities are presented in the following section of the report. The total operating costs were calculated as 12 percent of the capital expenditures, whereas maintenance costs are 5 percent. Presently, the total operating costs for the industry are $20 to $26 million while maintenance costs are about $10 million per year. These data can be used to estimate replacement costs, especially when total facilities (equipment and related structures) are to be replaced.

Capital and Operating Costs

General

Capital and operating costs for specific wastewater treatment facilities and unit costs, applying to the paper industry in general, have been extracted from the literature and various industrial sources. Table Nos. 8 and A-8 summarize this information. Table A-8 presents unit costs in terms of mill production and/or waste quantities. Data are presented only where enough information was available to determine a range of costs. Most of these data illustrate the wide variability in treatment costs within the industry.

Table 8

Summary of Typical Waste Treatment Systems

Treatment Facilities	Bleached Sulfate Mill									Bleached Sulfite Mill								
	Older			Present			Newer			Older			Present			Newer		
	S	M	L	S	M	L	S	M	L	S	M	L	S	M	L	S	M	L
Pretreatment																		
Grit Removal	ALL SYSTEMS																	
Bar Screen	ALL SYSTEMS																	
Primary Treatment																		
Gravity Clarifier	ALL SYSTEMS																	
Secondary Treatment																		
Nutrient Addition				P	P	P	P	P	P				P	P	P	P	P	P
Stabilization Basin	P	P	P															
Contact-Stabilization				P	P	P	P	P	P									
Conventional Activated Sludge													P	P	P	P	P	P
Gravity Clarifier				P	P	P	P	P	P				P	P	P	P	P	P
Sludge Disposal																		
Gravity Thickener		P	P															
Vacuum Filter	P	P	P	P	P								P	P				
Centrifuge						P	P	P	P						P	P	P	P

S - Small Mill M - Medium Mill L - Large Mill P - Process Chosen

Table No. 9 contains a breakdown of total operating costs as a percentage of capital costs and individual operating costs as a percentage of total operating costs. Although mean percentages are shown in this table, this information was derived from data covering a small portion of the industry providing wastewater treatment.

The tabulated cost data, although representative of industry practice, were not specifically applied to the economic evaluation of treatment facilities designed for the different production technologies as discussed in the following section.

Technology Related Costs

Tables A-9, A-10, and A-11 summarize the capital costs of wastewater treatment facilities specifically designed for small, medium, and large integrated paper and pulp mills, both bleached sulfate and sulfite. The production levels, as shown in the tables, were selected to represent small, medium, and large manufacturing operations in the older, present and newer mills. The bases for selecting bleached sulfate and sulfite mills for consideration were:

1. These mills discharge wastewaters of different characteristics; therefore, they require separate approaches to wastewater treatment.

2. More design experience, especially in secondary treatment, is available for these mills than others in the paper industry.

3. During the industry study, about 50 percent of the data obtained was in regard to production from these two processes. (Nearly 70 percent of unbleached sulfate and sulfite mills are included since these wastewaters exhibit treatability characteristics similar to those from the bleached operations.)

Wastewater characteristics and quantities selected for the various mill sizes were combined to define the design basis for treatment facilities. The treatment facilities were designed and economically evaluated according to usual engineering practices and average unit cost data for equipment and construction materials. The summary tables do not include all processes that can be used in pulp and paper mills' wastewater treatment, but instead,

Table 9

General Operating Cost Functions

Basis	Percent of Capital Investment		Percent of Operating Costs	
	Range	Mean	Range	Mean
Total Operating Costs				
Primary Treatment[1]	7-20	10		
Primary and Secondary[1] Treatment	7-20	12		
Sludge Disposal[2]	10-50	30		
Individual Operating Costs				
Operating Labor			10-50	20
Maintenance			10-40	25
Labor			5-15	15
Materials			5-30	10
Chemicals (and Miscellaneous Supplies)			25-50	35
Power			10-50	20

[1] All "treatment" operating data includes sludge disposal.

[2] Limited data with respect to sludge disposal capital costs, presented as comparison to operating cost data for total treatment facilities.

represent those processes most commonly used which can readily be designed and economically evaluated. It should be emphasized that these data might not represent typical costs for wastewater treatment because only the major facilities were designed. The application of additional miscellaneous equipment and structures is a function of treatment efficiencies, site location, and pollution abatement philosophy of the individual mills. The costs do not include such items as wastewater pumping and piping, site preparation, relocation and/or development of utilities, instrumentation, neutralization facilities, control and laboratory buildings, or miscellaneous flow mixing, distribution, measurement, and discharge structures. Nominal excavation and backfill costs were included, but hauling and grading charges were omitted. For large treatment facilities, such as aerated lagoons, the land value was assumed to be $1,000 per acre in all cases. This value may vary from a very small cost for rural or company-owned land to multiples of this cost when land must be purchased from private parties and/or in urban areas.

In the older technology, manually cleaned grit removal facilities and bar screens were generally included in the system; however, when estimating the costs for such systems, costs for mechanically cleaned equipment were used as a basis since there were no cost data available on manually cleaned facilities. These were not usually designed or constructed according to standard parameters even though many of the older mills utilized settling basins for primary solids removal. Since these were generally designed according to available land area with little regard to hydraulic loading rates, it was not considered feasible to design a representative facility. Primary clarifiers were designed on an overflow basis of 800 gallons per day per square foot of surface area. (This is also the design basis for the present and newer technologies.) Stabilization basin costs are based on a retention time of one day in an earthen basin with off-the-shelf diffused air equipment.

Oxidation ponds were not designed because of very large area requirements associated with this type of facility, and they could not be constructed at land costs approaching $1,000 per acre. Sludge disposal costs include gravity thickeners and vacuum filtration systems.

Secondary treatment costs for the present and newer technologies include nutrient addition, activated sludge, and aerated lagoon treatment facilities. The nutrient addition facilities were designed to store chemicals for approximately 30 days with feed rates of one pound of phosphorus and five pounds of nitrogen per 100 pounds of BOD removed.

Facilities provided for the contact-stabilization modification of the activated sludge process were designed for 85 percent BOD removal when treating bleached Kraft wastewater; and conventional activated sludge facilities were designed for similar treatment of bleached sulfite wastewaters. Both systems include concrete aeration basins and platform-mounted mechanical aerators. Aerated lagoon systems were designed for 75 percent BOD removal from Kraft and sulfite mill wastewaters, and are of earthen construction with floating mechanical aerators. Centrifuge dewatering was included in the secondary sludge disposal costs. The costs do not include piping and sludge conveyance costs. Although the arrangement of centrifuges may vary with the individual application, normally these are an outside installation and require a massive concrete structure, if "isolation base" techniques are not used. Vacuum filtration costs do not include related piping, chemical addition facilities, nor nominal sludge conveyance equipment. As present in Table A-11, incineration costs for the newer treatment technology were derived from average cost data and are not representative of any particular incineration system. The application of a particular incineration system depends on many design parameters; i.e., heat value, inorganic or ash content, and solids concentration of the dewatered sludge.

To obtain total capital and operating costs, typical treatment systems were devised for each mill size and production technology. Data regarding these systems are presented in Table A-12. Since the capital costs for each facility used to develop the total cost do not contain costs for piping, pumping, electrical facilities, and miscellaneous structures, these costs were allowed for by using percentages derived from or based on experience.

The total capital costs presented in Table A-12 are probably the minimum costs needed to actually finance construction of an industrial wastewater treatment plant. There are a number of factors which have been previously reiterated that can directly affect the costs of wastewater treatment, but no meaningful estimate can be placed on these factors since they are specific to each mill. In some instances, these factors could nearly double some of the values shown in the table. The design of treatment systems incorporated gravity flow of wastewater through the treatment plant and the combined handling and dewatering of primary and secondary sludges, where applicable.

Operating costs for the treatment systems are also presented in Table A-12. Maintenance costs were based upon percentages of various capital costs: i.e., structures, one percent; mechanical, three percent; and pumping and piping, one percent. The maintenance and labor costs for each treatment unit are not presented for two reasons:

1. Insufficient data on specific treatment units and maintenance areas to subdivide manpower and material allocations.

2. The combination of overlapping of controls for treatment units.

Table A-12 also includes total capital costs in terms of mill capacity in tons of product per day and operating costs related to the production rate.

Treatment Cost Reduction by In-Plant Measures

The various in-plant measures for reducing wastewater flows and material losses have been discussed. Data is not available to compare the expenditures for in-plant equipment modifications and process changes with the cost savings in wastewater treatment costs by such measures. However, the overall savings in wastewater treatment facilities can be obtained by comparing the discharge from the present and newer technologies and resultant treatment costs.

For the wastewater treatment design basis, the following reductions in hydraulic and BOD loadings from the present to newer technology were used:

	Percent Reduction in Waste Discharge	
	Integrated Bleached Sulfate Mill	Integrated Bleached Sulfite Mill
Wastewater Flow	45	45
Total BOD Discharge	25	70

These reductions are attributed to the combined effects of all projected in-plant measures and improved recovery practices.

Of specific importance is the recovery of sulfite pulping chemicals which result in most of the 70 percent BOD reduction shown above.

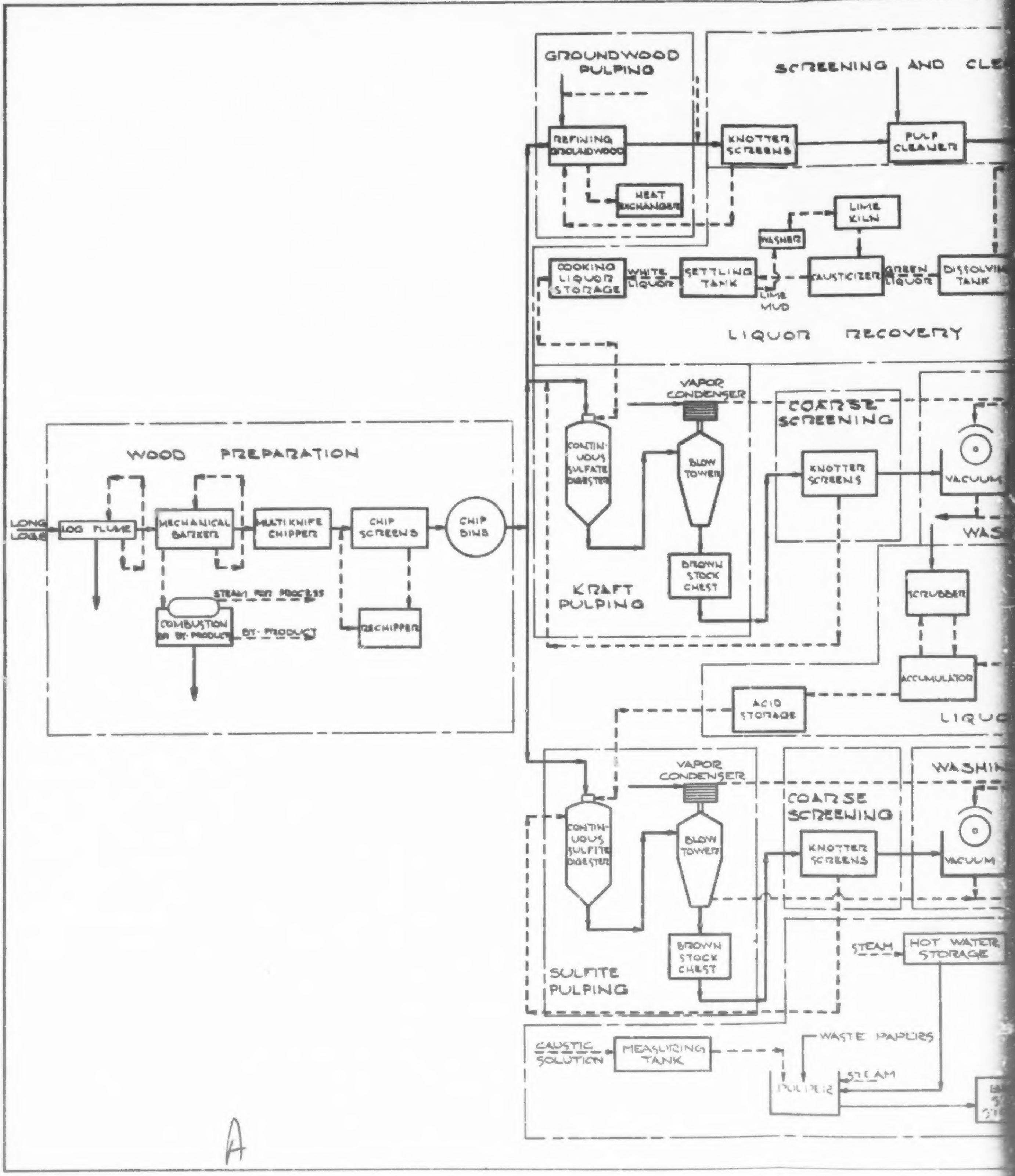
The results of these reductions are reflected in the difference in present and newer capital and operating costs on a production basis, as shown in Table A-12. The percent cost reductions vary with the size of mill but are approximately as follows:

1. 50 and 65 percent in total capital costs for bleached sulfate and sulfite operations respectively.

2. 30 and 65 percent in total operating costs for bleached sulfate and sulfite operations respectively.

It must be noted that the treatment systems designed for the present and newer technologies are not exactly the same, but are similar enough to permit comparison of cost data. Also, the percent savings figures only indicate savings in treatment costs by the application of almost all available in-plant wastewater reducing modifications in one particular mill. However, this is only economically feasible in a newly constructed mill and does not exclude the possibility that in-plant expenditures to reduce wastewater discharge might completely offset any saving in treatment costs.

APPENDIX A


GROUNDWOOD PULPING
REFINING GROUNDWOOD
HEAT EXCHANGER
SCREENING AND CLE
KNOTTER SCREENS
PULP CLEANER
LIME KILN
WASHER
COOKING LIQUOR STORAGE
WHITE LIQUOR
SETTLING TANK
LIME MUD
CAUSTICIZER
GREEN LIQUOR
DISSOLVING TANK
LIQUOR RECOVERY
WOOD PREPARATION
LONG LOGS
LOG FLUME
MECHANICAL BARKER
MULTI KNIFE CHIPPER
CHIP SCREENS
CHIP BINS
STEAM FOR PROCESS
COMBUSTION OF BY-PRODUCT
BY-PRODUCT
RECHIPPER
VAPOR CONDENSER
CONTIN-UOUS SULFATE DIGESTER
BLOW TOWER
BROWN STOCK CHEST
KRAFT PULPING
COARSE SCREENING
KNOTTER SCREENS
VACUUM
WAS
SCRUBBER
ACCUMULATOR
ACID STORAGE
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VAPOR CONDENSER
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BLOW TOWER
BROWN STOCK CHEST
SULFITE PULPING
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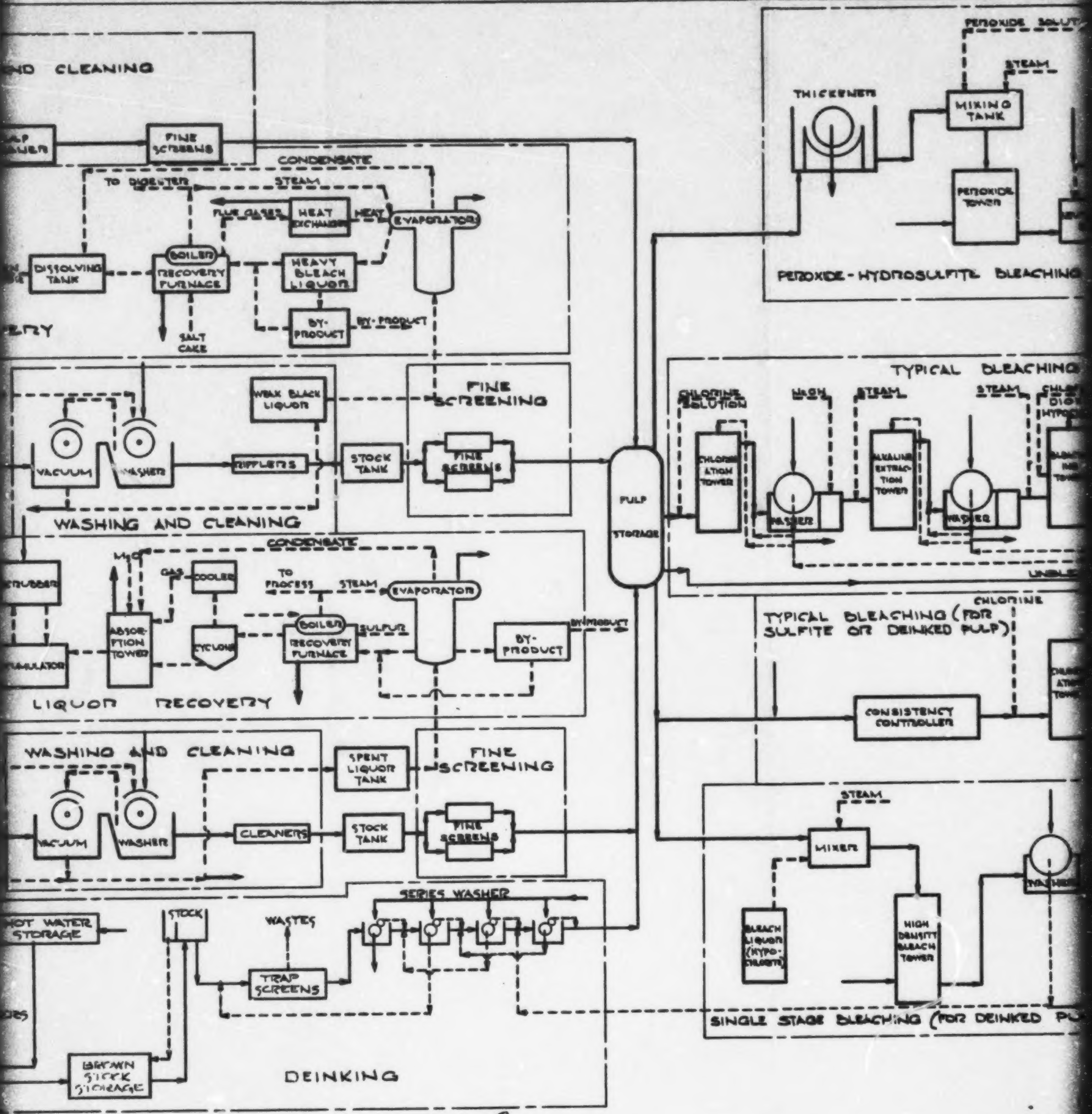

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STOCK TANK
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CONDENSATE
…RUBBER
H_2O
GAS
COOLER
TO PROCESS
STEAM
EVAPORATOR
ABSORPTION TOWER
CYCLONE
BOILER
RECOVERY FURNACE
SULFUR
BY-PRODUCT
BY-PRODUCT
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LIQUOR RECOVERY
WASHING AND CLEANING
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SERIES WASHER
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THICKENER
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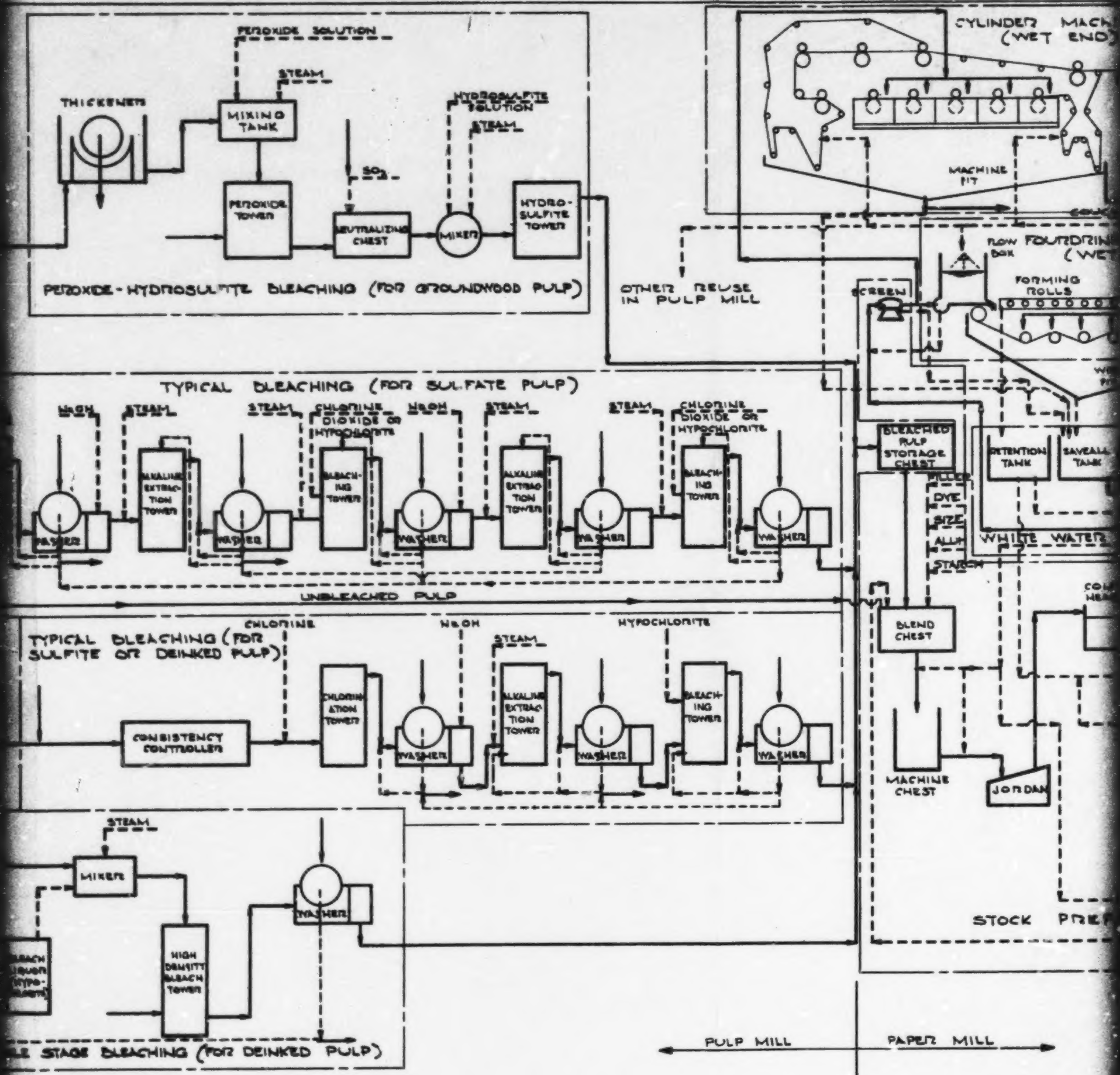
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STEAM
THICKENER
MIXING TANK
PEROXIDE TOWER
SO2
NEUTRALIZING CHEST
HYDROSULFITE SOLUTION
STEAM
MIXER
HYDRO-SULFITE TOWER
PEROXIDE-HYDROSULFITE BLEACHING (FOR GROUNDWOOD PULP)
OTHER REUSE IN PULP MILL
CYLINDER MACH
(WET END)
MACHINE PIT
FLOW BOX
FOURDRIN
(WET
SCREEN
FORMING ROLLS
TYPICAL BLEACHING (FOR SULFATE PULP)
NaOH
STEAM
STEAM
CHLORINE DIOXIDE OR HYPOCHLORITE
NaOH
STEAM
STEAM
CHLORINE DIOXIDE OR HYPOCHLORITE
WASHER
ALKALINE EXTRACTION TOWER
WASHER
BLEACHING TOWER
WASHER
ALKALINE EXTRACTION TOWER
WASHER
BLEACHING TOWER
WASHER
BLEACHED PULP STORAGE CHEST
RETENTION TANK
SAVEALL TANK
FILLER
DYE
SIZE
ALUM
STARCH
WHITE WATER
UNBLEACHED PULP
BLEND CHEST
TYPICAL BLEACHING (FOR SULFITE OR DEINKED PULP)
CHLORINE
NaOH
STEAM
HYPOCHLORITE
CONSISTENCY CONTROLLER
CHLORINATION TOWER
WASHER
ALKALINE EXTRACTION TOWER
WASHER
BLEACHING TOWER
WASHER
MACHINE CHEST
JORDAN
STEAM
MIXER
WASHER
BLEACH LIQUOR (HYPOCHLORITE)
HIGH DENSITY BLEACH TOWER
LE STAGE BLEACHING (FOR DEINKED PULP)
STOCK PREP
PULP MILL
PAPER MILL

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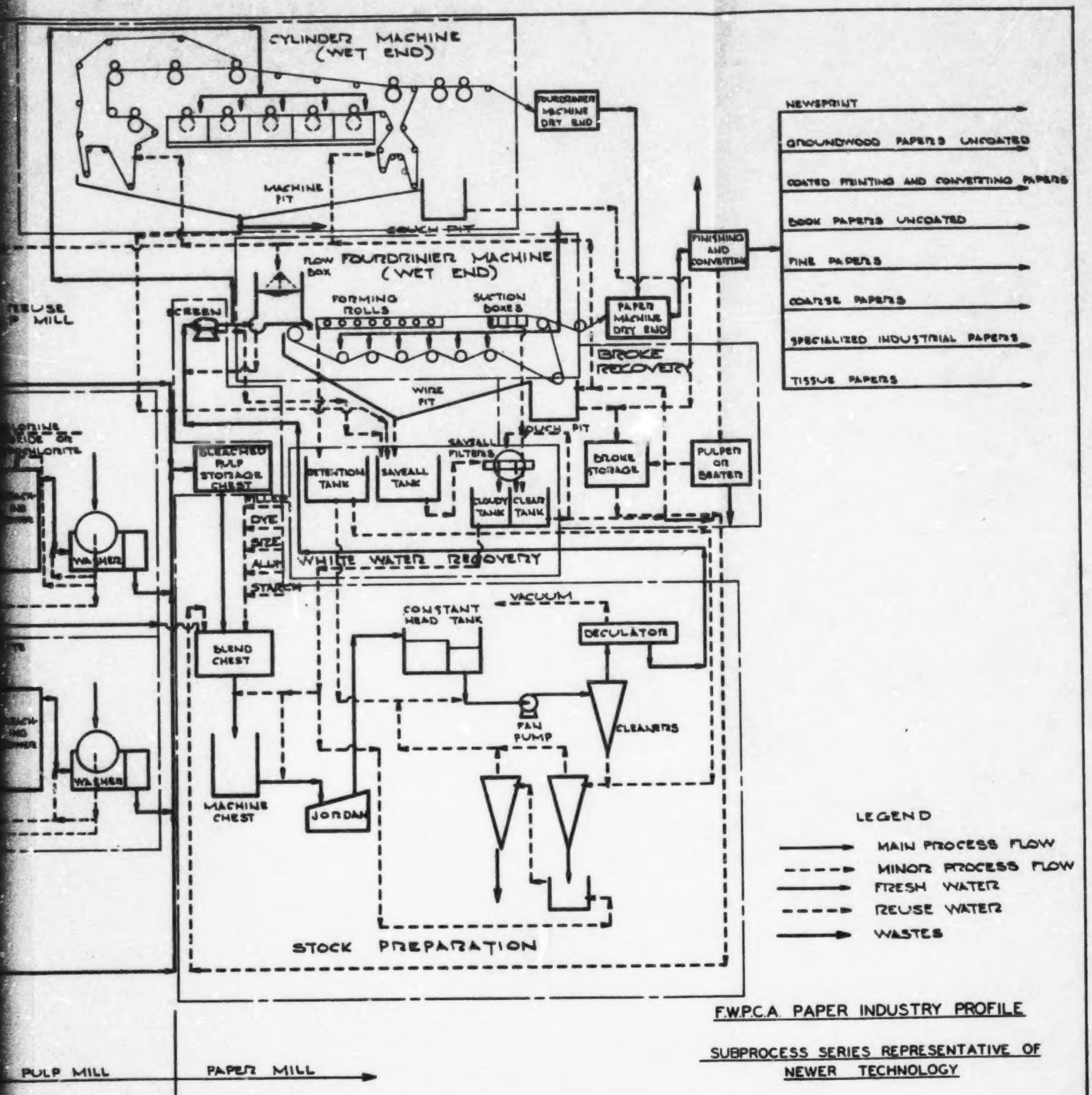
CYLINDER MACHINE (WET END)
FOURDRINIER MACHINE DRY END
MACHINE PIT
COUCH PIT
FOURDRINIER MACHINE (WET END)
FLOW BOX
FORMING ROLLS
SUCTION BOXES
SCREEN
PAPER MACHINE DRY END
FINISHING AND CONVERTING
BROKE RECOVERY
WIRE PIT
COUCH PIT
SAVEALL FILTERS
BROKE STORAGE
PULPER OR BEATER
BLEACHED PULP STORAGE CHEST
DETENTION TANK
SAVEALL TANK
CLOUDY TANK
CLEAR TANK
FILLER
DYE
SIZE
ALUM
STARCH
WHITE WATER RECOVERY
WASHER
WASHER
REUSE
P MILL
CONSTANT HEAD TANK
VACUUM
DECULATOR
BLEND CHEST
FAN PUMP
CLEANERS
MACHINE CHEST
JORDAN
STOCK PREPARATION
NEWSPRINT
GROUNDWOOD PAPERS UNCOATED
COATED PRINTING AND CONVERTING PAPERS
BOOK PAPERS UNCOATED
FINE PAPERS
COARSE PAPERS
SPECIALIZED INDUSTRIAL PAPERS
TISSUE PAPERS
LEGEND
MAIN PROCESS FLOW
MINOR PROCESS FLOW
FRESH WATER
REUSE WATER
WASTES
PULP MILL
PAPER MILL

F.W.P.C.A. PAPER INDUSTRY PROFILE

SUBPROCESS SERIES REPRESENTATIVE OF NEWER TECHNOLOGY

Prepared for F.W.P.C.A.	DRAWN GB	SCALE	DWG. NO. B-4
	DATE 9-28-67	W.O. NO. 300-01	

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Table A-1

Fundamental Manufacturing Processes - Subprocess Mix

Fundamental Processes and Alternative Subprocesses	Estimated Percentage of Plants Employing Process				
	1950	1963	1967	1972	1977
A. Wood Preparation:					
Without Water Reuse	55	10	2	1	1
With Water Reuse	42	85	90	84	69
Long Log Preparation	3	5	8	15	30
B. Pulping:					
Mechanical Pulping:					
Groundwood	13	7	3	2	1
Groundwood and Pretreated G.W. with water reuse	5	9	11	8	4
Refining Mechanical Pulp	0	1	2	5	8
Sub-total	18	17	16	15	13
Sulfate (Kraft) Pulping:					
Batch Process Without Water Reuse	19	6	4	3	1
Batch Process With Water Reuse	16	43	43	40	33
Continuous Process	1	4	9	17	30
Sub-total	36	52	56	60	64
Sulfite Pulping:					
Calcium Base Batch Process Without Water Reuse	25	5	4	3	1
Calcium Base With Water Reuse	2	10	8	5	4
Soluble Base With Liquor Recovery	2	2	3	4	6
Sub-total	29	17	15	12	11
Semichemical					
NSSC[2] Batch Process	0.6	0.1	0.05	0	0
NSSC Process With Water Reuse	0.1	1.15	1.35	1.3	0.9
Kraft Continuous Process	0	0.05	0.10	0.4	1.1
Sub-total	0.7	1.3	1.5	1.7	2
Deinking					
Cooking and Washing Without Water Reuse	8	3	2	1	1
Cooking and Washing With Water Reuse	1	4	5	6	6
Cooking and Flotation Separation	--	1	1	1	1
Sub-total	9	8	8	8	8
Others	7	5	4	3	2
Total Pulping	100	100	100	100	100
C. Bleaching:[1]					
Bleached Sulfate (Kraft)	11	25	28	30	32
Semi-bleached sulfate (Kraft)	2	7	9	13	17
Unbleached Sulfate (Kraft.	23	20	18	17	15
Bleached Sulfite	18	14	13	11	10
Unbleached Sulfite	11	3	2	1	1
Others[3]	35	31	30	28	26
D. Paper Machine:					
Cylinder Machine (Including Formers)	--	18	18	17	16
Fourdrinier Machine, Without Fiber and White Water Recovery	--	8	6	4	2
Fourdrinier Machine, With Fiber and White Water Recovery	--	74	76	79	82

[1] Percentage based on tons of paper products.

[2] Neutral Sulfite Semichemical.

[3] Include bleached and unbleached groundwood, semichemical, soda, and deinked pulp.

E. Bleaching												
Groundwood		--		--		--		--		--		4,000
Sulfate (Kraft)	14-124	60	92-280	180	216-294	240	8 -88	30		2.9	12,000-32,000	19,000
Sulfite	4- 44	15	126-409	205	131-415	220	17-44	25	2.9-6.8	3.8	9,000-30,000	15,000
Semichemical	--	--	--	--	--	--	--	--	--	--	--	--
Deinking	--	6	--	119	--	125	--	12	--	2.2	--	5,500
F. Paper Making[4]												
General	10-166	46	21-425	73	31-591	119	3-80	16	4.3-6.9	5	5,700-40,000	13,000
Products Related[5]:												
Newsprint	20-60	40	--	--	--	--	10-20	15	--	--	37,000	--
Uncoated Groundwood	--	--	--	--	--	--	--	--	--	--	--	--
Coated Printing Paper	--	--	--	--	--	--	--	--	--	--	--	--
Uncoated Book Paper	--	30	--	66	--	116	--	16	--	--	8,000-28,000	14,000
Fine Paper	47-100	73	--	80	--	155	15-40	20	--	--	9,000-40,000	18,000
Coarse Paper	10-30	20	--	--	--	--	10-25	15			2,000-29,000	10,000
Special Industrial Paper	200-400	300	--	--	--	--	140-170	155	--	--	20,000-100,000	--
Sanitary and Tissue Paper	50-100	50	--	150	--	200	15-30	22	--	--	8,000-37,000	14,000
G. Total Mill Effluent (Integrated Pulp and Paper Mills)												
Bleached Sulfate and Paper	50-200	170	150-1130	640	200-1300	810	30-220	120	--	--	39,000-54,000	45,000
Unbleached Sulfate and Paper[6]	--	50	--	460	--	510	--		--	--	--	27,000
Bleached Sulfite and Paper	40-100	100	560-1600	1044	600-1700	1140	235-430	330	--	--	40,000-70,000	55,000

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[1] Single pieces of data are entered under the "Range" column with parenthesis.

[2] The mean values shown are not truly statistical average; they are considered to be probable average values based on the available data.

[3] Deinking process includes pulping, screening, washing, and thickening.

[4] Wastewaters from papermaking include those from stock preparation, paper machine, and finishing and converting operations.

[5] See Table A-2 for classification of paper products.

[6] Data for integrated unbleached sulfate pulp and Paper Mill are generated by subtracting the portion of bleaching from the integrated bleached sulfate pulp and paper mill.

Table A-2

Percentage of Pulping Processes Employed as Related to Paper Products[1] In 1963

Pulping Processes Paper Products (SIC 2621)	Groundwood, Bleached and Unbleached	Sulfate					Sulfite					
		Bleached[6] Softwood	Bleached[6] Hardwood	Semi-Bleached[7]	Unbleached	Sub-Total	Bleached	Unbleached[8]	Sub-Total	Semi-Chemical	Waste Paper (Deinking)	Others[9]	Total
Newsprint	8.9	0.01	---	2.1	---	2.1	---	1.1	1.1	---	0.5	---	12.6
Groundwood Paper, Uncoated[2]	3.7	---	0.07	0.2	---	0.3	0.2	0.7	0.9	---	0.3	---	5.2
Coated Printing and Converting Paper	2.6	2.2	2.5	1.0	0.05	5.8	1.2	0.4	1.6	.02	1.5	0.5	12.2
Book Paper, Uncoated[3]	0.1	2.4	2.4	0.4	0.1	5.3	1.7	0.04	1.7	0.3	1.1	0.9	9.4
Fine Paper[4]	0.06	2.7	1.9	0.3	0.5	5.4	3.1	0.2	3.3	0.8	0.6	2.1	12.3
Coarse Paper	0.04	3.5	0.9	1.3	17.6	23.3	0.8	0.2	1.0	-	0.8	0.1	25.2
Special Industrial Paper	0.04	1.2	0.6	1.6	0.6	4.0	0.6	0.06	0.7	0.02	0.9	1.6	7.2
Sanitary and Tissue Paper	1.2	2.8	1.9	0.1	0.5	5.3	5.9	0.5	6.4	---	2.7	0.3	15.9
Total	16.6	14.8	10.3	7.0	19.4	51.5	13.5	3.2	16.7	1.3	8.4	5.5	100

[1] Total paper products (SIC 2621 only) produced in 1963 was 17,500,000 tons.

[2] Uncoated groundwood papers include publication and printing; converting; and miscellaneous groundwood papers.

[3] Uncoated book papers include publication and printing; converting; and miscellaneous book papers.

[4] Fine papers include writing paper; bristols; cover, text, and colored school paper; and thin paper.

[5] Coarse papers include wrapping paper; shipping sack paper; bag paper; converting paper; glassine, greaseproof, and vegetable parchment.

[6] Bleached Sulfate = Brightness over 72.

[7] Semi-bleached Sulfate = Brightness 45 - 72.

[8] Unbleached Sulfite = Brightness approximately 60.

[9] Other pulping processes include dissolving and special alpha, soda defibrated screenings, and all other fibrous material.

Table A-3

Wasteloads and Wastewater Quantities of Older Technology

Wasteload, in lbs/ton of Product

Processes	Suspended Solids Range[1]	Suspended Solids Mean[2]	Dissolved Solids Range[1]	Dissolved Solids Mean[2]	Total Solids Range[1]	Total Solids Mean[2]	BOD Range[1]	BOD Mean[2]	pH Range[1]	pH Mean[2]	Wastewater Quantities in gallons/ton Range[1]	Wastewater Quantities in gallons/ton Mean[2]
A. Wood Preparation	(40)	40		--		--	(44)	44	(7.2)	7.2	17,000-2[illegible],000	12,000
B. Pulping												
Groundwood	15~69	30		310	225~450	340	6~25	16	6~8.5		4,000-16,000	7,000
Sulfate (Kraft)												
Blow Pit Condenser	0~0.2	0.1		6	3~9	6	6~12	8	8~9.4	8.6	500	500
Uncollected Black Liquor	8~34	19		101	80~170	120	12~42	217	8.0~9.8	8.5	1,000-22,000	10,500
Evaporator Condensate	0.1~0.3	0.2		4	1.5~7.0	4	1.2~15	9	6.0~6.2	6.1	1,800~4,500	3,000
Causticizing Wastes	4~10	6		3	2~29	9	2~13	7	10.5~12	11.0	500~2,500	1,500
Green Dreg	1.6~3.2	2		21	15~36	23	0.5~2	1		--	(4,800)	4,800
Sub-total		27		135		162		52		9.8		20,300
Sulfite												
Digester	2~29	15		111	51~240	140	99~466	290	2.2~2.9	2.3	4,900-51,000	12,000
Other Sources	10~51	23		2294	300~3200	2300	30~360	72	2.5~3.7	3.5	1,200-13,000	2,600
Sub-total		38		2405		2440		362				14,600
Semichemical												
Digester	(2)	2	(3)	3	(5)	5	(10)	10		--	(500)	500
Other Sources	(45)	45	(105)	105	(150)	150	(33)	33		--	(11,500)	11,500
Sub-total		47		108		155		43		6.6		12,000
Deinking	82-1260	--	--	--	--	--	(300)	--	--	--	(83,000)	--
C. Pulp Screening												
Groundwood		--		--		--		--		--		--
Sulfate	1~18	9		71	(80)	80	12~25	18	(9.0)	9.0	4,500-15,000	9,600
Sulfite	11~15	14		21	24~53	35	1~8	3	4.0~6.3	5.2	4,200-14,200	9,100
Semichemical	(45)	45	(105)	105	(150)	150	(30)	30	(6.6)	6.6	(7,800)	7,800
D. Pulp Washing												
Groundwood		--		--		--		--		--		--
Sulfate	0.4~14	8		99	57~180	107	10~49	35	8.9~9.5	9.0	8,000-15,000	10,000
Sulfite	(25)	25		140	(165)	165		19	6.6~7.1	6.7	8,000-21,800	11,000
Semichemical	(1.02)	1.02			(400)	400	(85)	85	(7.3)	7.3	(6,000)	6,000
E. Pulp Thickening												
Groundwood	(14)	14	(93)	93	(107)	107	(47)	47	(5.0)	5.0	(10,000)	10,000
Sulfate	(10)	10	(61)	61	(71)	71	(7)	7	(8.4)	8.4	(15,000)	15,000
Sulfite	(4)	4		104	(108)	108	(19)	19	6.6~7.1	6.7	(17,000)	17,000
Semichemical	(1)	1		39	(40)	40	(5)	5	(7.4)	7.4	(14,000)	14,000

F. Bleaching												
Groundwood		--		--		--		--		--	~8,000	--
Sulfate		--		--	270-520	400		--	(4.5)	--	28,000-60,000	45,000
Sulfite	14-50	30	190-420	305	200-460	335	17-108	40	2.5-7.2	4.4	23,000-58,000	43,000
Semichemical	(76)	--	(1230)	--	(1300)	--	(126)	--	--	--	33,000-60,000	45,000
G. Paper Making[4]												
General	17-220	60	53-160	100	73-380	160	5-44	20	4.4-7.3	--	17,000-61,000	38,000
Products Related:[5]												
Newsprint		--		--		--		--		--		--
Uncoated Groundwood		--		--		--		--		--		--
Coated Printing Paper		--		--		--		--		--		--
Uncoated Book Paper		--		--		--		--		--		--
Fine Paper		--		--		--		--		--		48,000
Coarse Paper		--		--		--		--		--		27,000
Special Industrial Paper		--		--		--		--		--		94,000
Sanitary and Tissue Paper		--		--		--		--		--		18,400
H. Total Mill Effluent (Integrated Pulp and Paper Mills):												
Bleached Sulfate (Kraft) and Paper	80-370	200	560-1360	900	640-1730	1100	50-350	200	--	--	75,000-140,000	110,000
Unbleached Sulfate (Kraft) and Paper[6]		--		--	--	650		--		--	--	90,000
Bleached Sulfite and Paper	50-200	120	430-1790	1200	480-1980	1320	350-730	500	--	--	58,000-170,000	95,000

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[1] Single pieces of data are entered under the "Range" column with parenthesis.

[2] The mean values shown are not truly statistical average; they are considered to be probable average values based on the available data.

[3] Deinking process includes pulping, screening, washing, and thickening.

[4] Wastewaters from papermaking include those from stock preparation, paper machine, and finishing and converting operations.

[5] See Table A-2 for classification of paper products.

[6] Data for integrated unbleached sulfate pulp and Paper Mill are generated by subtracting the portion of bleaching from the integrated bleached sulfate pulp and paper mill.

Table A-4

Wasteloads and Wastewater Quantities of Today's Typical Technology

Processes	Wasteload, in lbs/ton of Product										Wastewater Quantities in gallons/ton	
	Suspended Solids		Dissolved Solids		Total Solids		BOD		pH			
	Range[1]	Mean[2]	Range[1]	Mean[2]	Range[1]	Mean[2]	Range[1]	Mean[2]	Range[1]	Mean[2]	Range[1]	Mean[2]
A. Wood Preparation	1.9-40	9		4	4-50	13	2-10	3	6.5-8.0	7.0	1,000-10,000	3,400
B. Pulping												
Groundwood		--		--		--		--		--		--
Sulfate (Kraft)												
Blow Tower	(3.7)	4		17	(21.0)	21	(1.3)	1	(12)	12.0	(1,000)	1,000
Dirty Condensate	0-0.5	0.1		4	6-11	7	6.5-9.0	8	9.5-10	10.0	950~1,900	1,200
Evaporator Ejector	0.06-0.2	0.1		2	1~3	2	1.6-4.5	3	9~10	9.5	290~640	300
Causticizing Waste	2.2~5.7	5		96	46-240	101	8.0-10.5	9	9-11.0	10.0	600~9,600	2,500
Green Dreg	(1.0)	1		21	(22)	22	(1.0)	1	(12)	12.0	(200)	200
Floor Drain	0.5-10	6		1	11.0-11.5	11	0.3-1.7	1	11.6-12	12.0	340~580	400
Sub-total		17		141		164		23	9.5~12.0			5,600
Sulfite												
Blow Tower	0.42-1.9	1		246	36-348	247	29-194	116	2.2-2.9	2.7	1,840~1,950	1,900
Condensate	0.05-0.2	0.1		47	18~87	47	48~71	66	2.3-3.1	2.6	750~1,700	1,100
Uncollected Liquor	0.3-43	21		84	50-515	105	50~61	53	2.2-2.6	2.4	2,000-10,000	7,500
Acid Plant Wastes	(5)	5	(5)	5	(10)	10		--	(1.2)	1.2	(300)	300
Boiler Blowdown	(2)	2		--	(22)	22	(0.05)	0.05		11.0	(100)	100
Sub-total		29		382		411		235	1.2-2.9			10,900
Semichemical												
Blow Tower	(2)	2	(6)	6	(8)	8	(1)	1		4.0	(1,000)	1,000
Condensate	(0.1)	0.1	(2)	2	(2)	2	(3)	3		3.5	(2,000)	2,000
Recovery system	(9)	9	(111)	111	(150)	150	(8)	8		--	(2,000)	2,000
Uncollected Liquor	(11)	11	(29)	29	(40)	40	(18)	18		2.5	(2,000)	2,000
Sub-total	(22)	22		148		200		30	2.5-4.0			7,000
Deinking												
All sources[3]				--		--	11-23	--		--	9,700-36,000	--
C. Pulp Screening												
Groundwood		--		--		--		--		--		--
Sulfate (Kraft)	5-8.0	4		58	60-63	62	10-18	14	9-10	10.0	900~9,600	3,600
Sulfite	1.7-14	8		19		27	22-10.7	8	5.4-5.7	5.6	1,700-14,300	6,000
Semichemicals		--		--		--		--		--		--
Deinking		--		--		--		--		--		--
D. Pulp Washing and Thickening												
Groundwood (No Washing)	9~14	11		44	51-107	73	22-46	33	5.0-6.25	6.0	4,800-10,000	7,500
Sulfate (Kraft)	10-30	15		127	94-180	142	10-35	25	8.9-9.4	9.0	3,000-11,000	7,000
Sulfite	6.5-9.0	8		123	68-1037	131	7.4-34.0	18	2.4-3.9	2.9	1,800-15,000	7,500
Semichemical	0.9-6.0	3		90	42-141	93	10-42	24	7.0-7.9	7.4	2,400~7,800	5,400
Deinking		--		--		--		--		--		--

Table A-5

Wasteloads and Wastewater Quantities of Newer Technology

Processes	Wasteload, in lbs/ton of Product										Wastewater Quantities in gallons/ton	
	Suspended Solids		Dissolved Solids		Total Solids		BOD		pH			
	Range[1]	Mean[2]	Range[1]	Mean[2]	Range[1]	Mean[2]	Range[1]	Mean[2]	Range[1]	Mean[2]	Range[1]	Mean[2]
A. Wood Preparation	(2)	2		2	(4)	4	(0.2)	0.2	(6.9)	6.9	(1,700)	1,700
B. Pulping												
Refining Groundwood	(16)	16		34	(50)	50	(10)	10	(6.9)	6.9	(2,000)	2,000
Sulfate (Kraft)												
Blow Tower		--		--		--		--		--		--
Causticizing Waste	1.8~4.5	2		44	22~56	46	9.0~9.3	9	11.6~12	11.8		2,700
Evaporator Ejector	0.27~0.42	0.3		10	6.3~11	10	8.0~10.0	9	9.2~9.5	9.3		400
Green Dreg	(0.6)	0.6		19.4	(20)	20	(1.0)	1	(12.0)	12.0		900
Condensate	0.06~0.12	0.1		5	2.1~6.3	5	1.6~3.5	2	9~10	9.5		600
Sub-total		3.0		78		81		21				4,600
Sulfite												
Digester	3.8~12.5	8		74	36~120.	87	10~18	14	2.0~2.2	2.2	320~7,100	2,100
Condensate	0.05~0.12	0.1		65	41~87	65	14~48	31	2.3~3.1	2.7	750~1,700	1,100
Acid Plant		--		--		--		--		0.5	(1,100)	1,100
By-product Plant	(3)	3		150	(153)	153	(21)	21	(4.5)	4.5	(2,000)	2,000
Other Sources		--		--		--		4		--		--
Sub-total		11		289		305		70		--		6,300
C. Pulp Screening					Generally No Waste Produced							
D. Pulp Washing, Thickening, Cleaning												
Refining Groundwood	2~11	6		21	5~51	27	2~22.3	10	6~6.5	6.2	180~4,800	1,900
Sulfate	2~30	15		35	2.3~94	50	2.0~12	8	9~10	9.5	1,000~2,400	2,000
Sulfite	2.8~8.1	6		62	42~93	68	3.9~18	11	2.4~4.7	3.9	1,800~7,800	4,100
E. Bleaching												
Groundwood		--		--		--		--		--		--
Sulfate	(2)		(123)		(125)		(8)		2.7-6.1	4.4	11,000-12,000	11,500
Sulfite	(3)		(187)		(90)		6-8	7	(7.0)	--	5,200-6,800	6,000
Deinking	--	--	--	--	--	--	--	--	--	--	--	--
F. Paper Making[3]												
General	2-38	30	24-66	40	26-104	70	2-16	10	(4.5)		4,500-11,000	7,500

G. Total Mill Effluent (Integrated Pulp and Paper Mills)												
Bleached Sulfate and Paper	--	90		300		390		90			--	25,000
Unbleached Sulfate and Paper		80		180		260		80				16,000
Bleached Sulfite and Paper	10-70	50	300-500	400	300-550	450	60-300	100	--	--	10,000-40,000	30,000

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[1] Single pieces of data are entered under the "Range" column with parenthesis.

[2] The mean values shown are not truly statistical average; they are considered to be probable average values based on the available data.

[3] Wastewaters from papermaking include those from stock preparation, paper machine, and finishing and converting operations.

[4] Data for integrated unbleached sulfate pulp and Paper Mill are generated by subtracting the portion of bleaching from the integrated bleached sulfate pulp and paper mill.

Table A-6

Monthly Variation of Paper Production in 1964

Types of Paper	Paper Production in 1000 Tons												Ratio of Maximum to Minimum Monthly Production
	Jan.	Feb.	Mar.'	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
Newsprint	201.3	177.9	194.2	192.9	205.3	198.5	178.8	204.2	183.3	196.9	185.8	179.1	1.14
Groundwood Paper, Uncoated:													
Publication and Printing	68.9	64.0	62.2	70.0	69.0	66.8	59.7	65.2	62.1	74.6	64.6	65.1	1.25
Converting	10.8	10.7	10.4	10.7	10.9	11.5	10.2	12.3	10.5	11.8	11.3	10.4	1.20
Miscellaneous Groundwood	2.8	2.6	2.7	2.5	2.2	3.5	2.0	2.4	2.5	2.5	1.6	2.4	2.20
Coated Printing and Converting Paper:													
Coated, One Side	25.9	25.2	27.7	26.2	28.9	27.1	26.5	28.3	25.9	27.2	25.3	26.8	1.15
Coated, Two Sides	202.5	184.5	189.6	190.9	188.4	186.5	182.6	188.7	179.8	204.5	205.3	197.4	1.14
Book Paper, Uncoated:													
Publication and Printing	101.2	100.0	104.8	103.6	103.6	105.6	93.9	97.5	96.3	108.5	104.8	101.2	1.15
Converting	60.6	56.0	65.2	67.5	69.8	70.6	64.4	66.7	59.8	65.2	61.4	59.8	1.26
Miscellaneous Book	0.2	0.4	0.4	0.4	0.4	0.3	0.2	0.4	0.3	0.3	0.3	0.2	2.00
Fine Paper:													
Writing Paper	138.6	133.1	143.1	147.9	146.5	143.2	130.6	142.5	141.2	153.6	140.9	139.2	1.17
Bristols	11.9	11.9	12.9	13.2	14.0	13.2	11.6	14.6	12.4	13.5	11.8	14.1	1.26
Cover, Text, and Colored School Paper	17.0	16.2	16.0	16.0	14.8	15.1	11.8	14.2	13.2	13.9	13.7	13.9	1.44
Thin Paper	14.5	14.8	14.3	15.0	14.5	15.2	14.6	15.2	14.8	16.4	14.1	15.2	1.16
Coarse Paper:													
Wrapping Paper	50.7	47.8	47.7	48.4	50.9	50.1	45.4	55.4	48.9	52.9	50.4	52.3	1.22
Shipping Sack Paper	87.5	81.7	89.4	86.1	79.3	72.7	77.1	78.6	70.4	88.3	72.7	78.1	1.27
Bag Paper	116.9	129.0	122.1	120.6	120.8	113.5	113.3	131.6	127.7	133.9	129.2	121.9	1.18
Converting Paper	99.5	95.3	102.2	107.0	103.0	93.4	85.3	91.6	91.7	102.7	94.5	90.2	1.25
Glassine, Greasproof, and Vegetable Parchment, all end - uses	17.4	15.5	'15.3	17.0	16.1	16.1	15.9	15.2	15.9	18.6	16.1	16.9	1.22
Special Industrial Paper (Including absorbent paper)													
Sanitary and Tissue Paper:													
Toweling	60.8	56.4	57.8	65.9	58.6	55.6	58.6	61.5	62.9	74.7	60.1	60.1	1.34
Toilet Tissue	95.3	86.5	92.1	98.7	93.1	88.7	93.1	95.4	89.8	103.1	85.4	87.6	1.21
Napkin	23.1	20.5	22.8	23.4	25.0	22.6	20.7	22.1	21.2	24.8	21.8	21.0	1.22
Facial Tissue	30.3	30.2	28.6	28.3	26.4	26.0	24.4	25.1	24.1	28.3	26.0	27.7	1.26
Other Sanitary Tissue Stock Wadding	7.3	6.9	7.1	6.8	6.2	6.6	5.6	6.8	6.3	7.7	7.1	6.6	1.37
Tissue Paper, except sanitary and thin paper	20.2	18.6	19.5	20.9	19.5	18.2	17.7	18.2	18.2	19.9	17.9	18.2	1.18
Total Paper	1,546.1	1,460.7	1,531.9	1563.5	1,546.0	1,498.4	1,421.0	1,530.5	1,461.4	1,635.4	1502.6	1,483.1	1.15

[1] From "Current Industrial Reports", Series M 26A (64)- 13, U. S. Department of Commerce, Bureau of the Census, 1964

Table A-7

Waste Reduction Efficiency

Processes and Alternative Subprocesses	Waste Reduction Efficiency (percent)				
	Suspended Solids	Dissolved Solids	Total Solids	BOD_5	Waste Water Volume
A. Wood Preparation					
Without Water Reuse	0	--	--	0	0
With Water Reuse	77	--	--	93	72
Long Log Preparation	95	--	--	99	86
B. Pulping					
Mechanical Pulping					
Groundwood	0	0	0	0	0
Groundwood or Pretreated Groundwood With Water Reuse	--	--	--	--	--
Refining Mechanical Pulp	46	89	85	37	71
Sulfate (Kraft) Pulping					
Batch Process Without Water Reuse	0	0	0	0	0
Batch Process With Water Reuse	37	-4	-1	56	72
Continuous Process	89	42	47	60	77
Sulfite Pulping					
Calcium Base Batch Process Without Water Reuse	0	0	0	0	0
Calcium Base With Water Reuse	24	84	83	35	29
Soluble Bases With Liquor Recovery	71	84	87	80	57
Semichemical Pulping					
NSSC Batch Process	0	0	0	0	0
NSSC Kraft Batch Process With Water Reuse	53	-26	-29	30	32
Deinking					
Cooking and Washing Without Water Reuse	--	--	--	--	0
Cooking and Washing With Water Reuse	--	--	--	--	66
C. Pulp Screening					
Sulfate (Kraft) Pulp					
Screening Without Water Reuse	0	0	0	0	0
Screening With Partial Water Reuse	55	18	23	22	62
Screening and Cleaning With Water Reuse	(100)	(100)	(100)	(100)	(100)
Sulfite					
Screening Without Water Reuse	0	0	0	0	0
Screening With Partial Water Reuse	43	9	23	56	54
Screening and Cleaning With Water Reuse	(100)	(100)	(100)	(100)	(100)
D. Pulp Washing and Thickening					
Mechanical Pulp					
Thickening and Cleaning With Decker	0	0	0	0	0
Thickening With Vacuum Filtration	21	52	30	30	25
Thickening and Cleaning With V.F.	57	77	75	79	81
Sulfate (Kraft) Pulp					
Diffuser Washing With Decker Thickening	0	0	0	0	0
Vacuum Filter Washing and Thickening	17	21	20	40	72
Multistage V.F. Washing and Thickening	17	78	72	81	80
Sulfite Pulp					
Diffuser Washing With Decker Thickening	0	0	0	0	0
Vacuum Filter Washing and Thickening	72	50	52	52	62
Multistage V.F. Washing and Thickening	79	75	75	71	90
E. Bleaching					
Sulfate (Kraft) Pulp					
Bleaching Without Water Reuse	--	--	0	--	0
Bleaching With Low Degree of Water Reuse	--	--	40	--	58
Bleaching With High Degree of Water Reuse	--	--	69	--	74
Sulfite Pulp					
Bleaching Without Water Reuse	0	0	0	0	0
Bleaching With Low Degree of Water Reuse	50	32	34	37	67
Bleaching With High Degree of Water Reuse	80	80	80	72	86
F. Paper Making					
Without White Water Recovery	0	0	0	0	0
With White Water Recovery	34	27	25	20	60
With Improved White Water Recovery	50	60	56	50	77

Table A-8

Unit Waste Removal Cost Summary[1]

Treatment Method (or equipment)	Unit Capital Costs					Unit Operating Costs			
	$/Physical Unit	$/Mill Capacity in TPD	$/Waste Unit/Day			$/Mill Production in TPD	$/Waste Unit		
			MG of Flow	Pound BOD$_5$ Removed	Ton of Dry Waste Sludge		MG of Flow	Pound BOD$_5$ Removed	Ton of Dry Waste Sludge
Primary Treatment									
Chemical Flocculation			2,000-100,000				10-20, low dosage 60-70, high dosage		
Sedimentation Basin		500				0.25-0.30			
Gravity Clarifier	50/dia. ft. < 100 ft. dia. 150/dia. ft. > 125 ft. dia.	800-1,500				0.20-0.75			
Secondary Treatment									
Nutrient Addition				0.01-0.40			10-40	0.005-0.02	
Oxidation Pond		1,000-2,000				0.25-0.35			
Trickling Filter	100/cubic yd., plastic media								
Aerated Lagoon	200-2,000/1,000 cubic ft.					0.10-0.50			
Activated Sludge	2,000-4,000/1,000 cubic ft.	3,000-5,000	60,000-150,000			1.00-2.50			
Irrigation	500-800/acre, piping and pumping 200-300/acre, underdrains[2] 600-1,700/acre, complete[3], [4]		40,000- 80,000			0.30-0.70	5-25		
Sludge Handling and Disposal									
Vacuum Filtration System	200-400/square ft. of filter area				2,000-10,000				2-12
Centrifuge system	300-1,000/GPM of sludge								2- 9
Incineration					10,000-80,000				6-26

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[1] Primarily published data from full-scale facilities.

[2] When needed.

[3] Excluding cost of land.

Table A-9

Capital Costs and Economic Life of Wastewater Treatment Facilities

Older Technology

Treatment Facilities	Economic Life (years)	Capital Costs (dollars)					
		Bleached Sulfate Integrated Mill			Bleached Sulfite Integrated Mill		
		Small (100 TPD)[1]	Medium (250 TPD)	Large (500 TPD)	Small (50 TPD)	Medium (150 TPD)	Large (300 TPD)
Pretreatment							
Grit Removal	25	17,000	23,000	28,000	13,000	18,000	23,000
Bar Screen	25	33,000	42,000	49,000	16,000	35,000	42,000
Primary Treatment							
Gravity Clarifier	25	138,000	287,000	505,000	78,000	178,000	297,000
Secondary Treatment							
Stabilization Basin	30	19,000	48 000	96,000	10,000	26,000	51,000
Sludge Disposal[2]							
Gravity Thickener	20	8,000	16,000	22,000	6,000	8,000	14,000
Vacuum Filter System	20	72,000	163,000	319,000	33,000	72,000	143,000

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[1] Mill capacity in tons of product per day.

[2] Sludge includes only primary.

Table A-10

Capital Costs and Economic Life of Wastewater Treatment Facilities

Present Technology

Treatment Facilities	Economic Life (years)	Capital Costs (dollars)					
		Bleached Sulfate Integrated Mill			Bleached Sulfite Integrated Mill		
		Small (100 TPD)[1]	Medium (500 TPD)	Large (1000 TPD)	Small (50 TPD)	Medium (150 TPD)	Large (750 TPD)
Pretreatment							
Grit Removal	25	13,000	21,000	26,000	11,000	15,000	26,000
Bar Screen	25	16,000	39,000	47,000	14,000	31,000	46,000
Primary Treatment							
Gravity Clarifier	25	74,000	235,000	449,000	49,000	114,000	421,000
Secondary Treatment							
Nutrient Addition	20	9,000	13,000	37,000	10,000	19,000	43,000
Activated Sludge[2]	20	134,000	408,000	769,000	121,000	329,000	1,217,000
Aerated Lagoon	30	215,000	1,044,000	2,088,000	155,000	458,000	2,180,000
Secondary Clarifier	20	114,000	281,000	475,000	75,000	158,000	450,000
Sludge Disposal[3]							
Gravity Thickener	20						
Activated Sludge		12,000	30,000	50,000	8,000	20,000	62,000
Aerated Lagoon		8,000	26,000	46,000	5,000	12,000	30,000
Vacuum Filter System	20						
Activated Sludge		91,000	455,000	910,000	84,000	252,000	1,205,000
Aerated Lagoon		84,000	401,000	840,000	53,000	101,000	505,000
Centrifuge	20						
Activated Sludge		29,000	117,000	195,000	29,000	68,000	273,000
Aerated Lagoon		29,000	117,000	234,000	29,000	29,000	117,000

[1] Mill capacity in tons of product per day.

[2] Contact-stabilization process for sulfate mill; conventional activated sludge process for sulfite mill.

[3] Sludge includes primary and that generated in activated sludge or aerated lagoon treatment.

Table A-11

Capital Costs and Economic Life of Wastewater Treatment Facilities

Newer Technology

Treatment Facilities	Economic Life (years)	Capital Costs (dollars)					
		Bleached Sulfate Integrated Mill			Bleached Sulfite Integrated Mill		
		Small (300 TPD)[1]	Medium (700 TPD)	Large (1500 TPD)	Small (150 TPD)	Medium (350 TPD)	Large (750 TPD)
Pretreatment							
Grit Removal	25	15,000	20,000	25,000	12,000	26,000	21,000
Bar Screen	25	30,000	37,000	45,000	16,000	32,000	39,000
Primary Treatment							
Gravity Clarifier	25	106,000	198,000	369,000	74,000	132,000	235,000
Secondary Treatment							
Nutrient Addition	20	13,000	22,000	40,000	9,000	16,000	29,000
Activated Sludge[2]	20	233,000	374,000	692,000	142,000	280,000	485,000
Aerated Lagoon	30	365,000	851,000	1,826,000	229,000	503,000	1,061,000
Secondary Clarifier	20	149,000	237,000	423,000	114,000	178,000	281,000
Sludge Disposal[3]							
Gravity Thickener	20						
Activated Sludge		9,000	13,000	23,000	5,000	9,000	14,000
Aerated Lagoon		7,000	11,000	20,000	3,000	6,000	9,000
Centrifuge	20						
Activated Sludge		40,000	78,000	195,000	29,000	40,000	117,000
Aerated Lagoon		40,000	78,000	156,000	29,000	29,000	40,000
Incineration	20						
Activated Sludge		400,000	900,000	1,900,000	250,000	500,000	1,000,000
Aerated Lagoon		350,000	800,000	1,650,000	150,000	300,000	600,000

[1] Mill capacity in tons of product per day.

[2] Contact-stabilization process for sulfate mill; conventional activated sludge process for sulfite mill.

[3] Sludge includes primary and that generated in activated sludge or aerated lagoon treatment.

Table A-12

Capital and Operating Costs for "Typical" Treatment Systems

	Bleached Sulfate									Bleached Sulfite								
	Older			Present			Newer			Older			Present			Newer		
	Small	Medium	Large	Small	Medium	Large	Small	Medium	Large	Small	Medium	Large	Small	Medium	Large	Small	Medium	Large
ital Costs																		
oncrete Structures	123,000	271,000	488,000	168,000	583,000	981,000	240,000	460,000	884,000	50,000	119,000	208,000	195,000	665,000	1,074,000	169,000	329,000	613,000
echanical	155,000	299,000	420,000	281,000	869,000	990,000	346,000	506,000	904,000	56,000	111,000	154,000	239,000	614,000	1,512,000	226,000	360,000	577,000
umps and Piping	45,000	142,000	225,000	112,000	363,000	493,000	147,000	241,000	446,000	27,000	57,000	90,000	108,000	320,000	645,000	99,000	172,000	299,000
lectrical	16,000	53,000	85,000	41,000	136,000	184,000	55,000	90,000	167,000	10,000	22,000	34,000	40,000	120,000	242,000	37,000	65,000	111,000
iscellaneous Structures	45,000	142,000	226,000	112,000	363,000	492,000	147,000	241,000	447,000	27,000	58,000	90,000	108,000	320,000	645,000	99,000	172,000	299,000
al Capital Costs	384,000	907,000	1,444,000	714,000	2,314,000	3,140,000	935,000	1,538,000	.848,000	170,000	367,000	576,000	690,000	2,039,000	4,118,000	630,000	1,098,000	1,899,000
ital Cost/Mill Capicity in TPD	3,840	3,630	2,890	7,140	4,650	3,140	3,120	2,200	1,900	3,420	2,450	1,920	1,380	1,360	5,500	4,200	3,140	2,500
al Operating Costs																		
aintenance																		
Structural	1,200	2,700	4,900	1,700	5,800	9,800	2,400	4,600	8,[illegible]	500	1,200	2,100	2,000	6,700	10,700	1,700	3,300	6,100
Mechanical	4,700	9,000	12,600	8,400	26,000	29,800	10,400	15,200	27,1[illegible]	1,700	3,300	4,600	7,200	18,100	45,400	6,800	10,800	17,300
Pumping and Piping	500	1,400	2,200	1,100	3,600	4,900	1,500	2,400	4,500	300	600	900	1,100	3,200	6,500	1,000	1,700	3,000
perating Labor	43,800	58,400	73,000	58,400	58,400	73,000	58,400	58,400	58,400	43,800	58,400	73,000	58,400	58,400	73,000	58,400	58,400	58,400
hemical Costs																		
H_3PO_4 at 211[illegible]/ton				6,900	34,600	69,000	15,600	36,200	77,500				8,300	25,000	124,500	7,500	17,600	37,700
NH_3 at 8[illegible]/ton				28,100	140,000	281,000	63,000	147,000	315,000				33,600	101,000	506,000	30,700	71,500	153,000
ower at [illegible].01/KW-hr.	11,400	16,700	93,000	18,100	50,200	106,600	25,600	53,300	107,000	10,800	16,000	27,500	22,600	50,600	196,800	19,000	36,000	70,700
al Annual Operating Costs	61,600	88,200	185,700	122,700	318,600	574,100	176,900	317,100	598,400	57,100	79,500	108,100	133,200	263,000	962,900	125,100	199,300	346,200
rating Cost Mill uction in Tons	1.70	1.00	1.00	3.36	1.74	1.60	1.60	1.24	1.10	3.12	1.45	1.00	7.30	4.80	3.50	2.30	1.56	1.30

Table A-12

Capital and Operating Costs for "Typic

Bleached Sulfate

	Older			Present			Newer	
	Small	Medium	Large	Small	Medium	Large	Small	Medium
Capital Costs								
Concrete Structures	123,000	271,000	488,000	168,000	583,000	981,000	240,000	460,000
Mechanical	155,000	299,000	420,000	281,000	869,000	990,000	346,000	506,000
Pumps and Piping	45,000	142,00C	225,000	112,000	363,000	493,000	147,000	241,000
Electrical	16,000	53,000	85,000	41,000	136,000	184,000	55,000	90,000
Miscellaneous Structures	45,000	142,000	226,000	112,000	363,000	492,000	147,000	241,000
Total Capital Costs	384,000	907,000	1,444,000	714,000	2,314,000	3,140,000	935,000	1,538,000
Capital Cost/Mill Capicity in TPD	3,840	3,630	2,890	7,140	4,630	3,140	3,120	2,200
Annual Operating Costs								
Maintenance								
Structural	1,200	2,700	4,900	1,700	5,800	9,800	2,400	4,600
Mechanical	4,700	9,000	12,600	8,400	26,000	29,800	10,400	15,200
Pumping and Piping	500	1,400	2,200	1,100	3,600	4,900	1,500	2,400
Operating Labor	43,800	58,400	73,000	58,400	58,400	73,000	58,400	58,400
Chemical Costs								
H_3PO_4 at \$110/ton				6,900	34,600	69,000	15,600	36,200
NH_3 at \$90/ton				28,100	140,000	281,000	63,000	147,000
Power at \$0.01/KW-hr.	11,400	16,700	93,000	18,100	50,200	106,600	25,600	53,300
Total Annual Operating Costs	61,600	88,200	185,700	122,700	318,600	574,100	176,900	317,100
Operating Cost/Mill Production in Tons	1.70	1.00	1.00	3.36	1.74	1.60	1.60	1.24

A

-12

"Typical" Treatment Systems

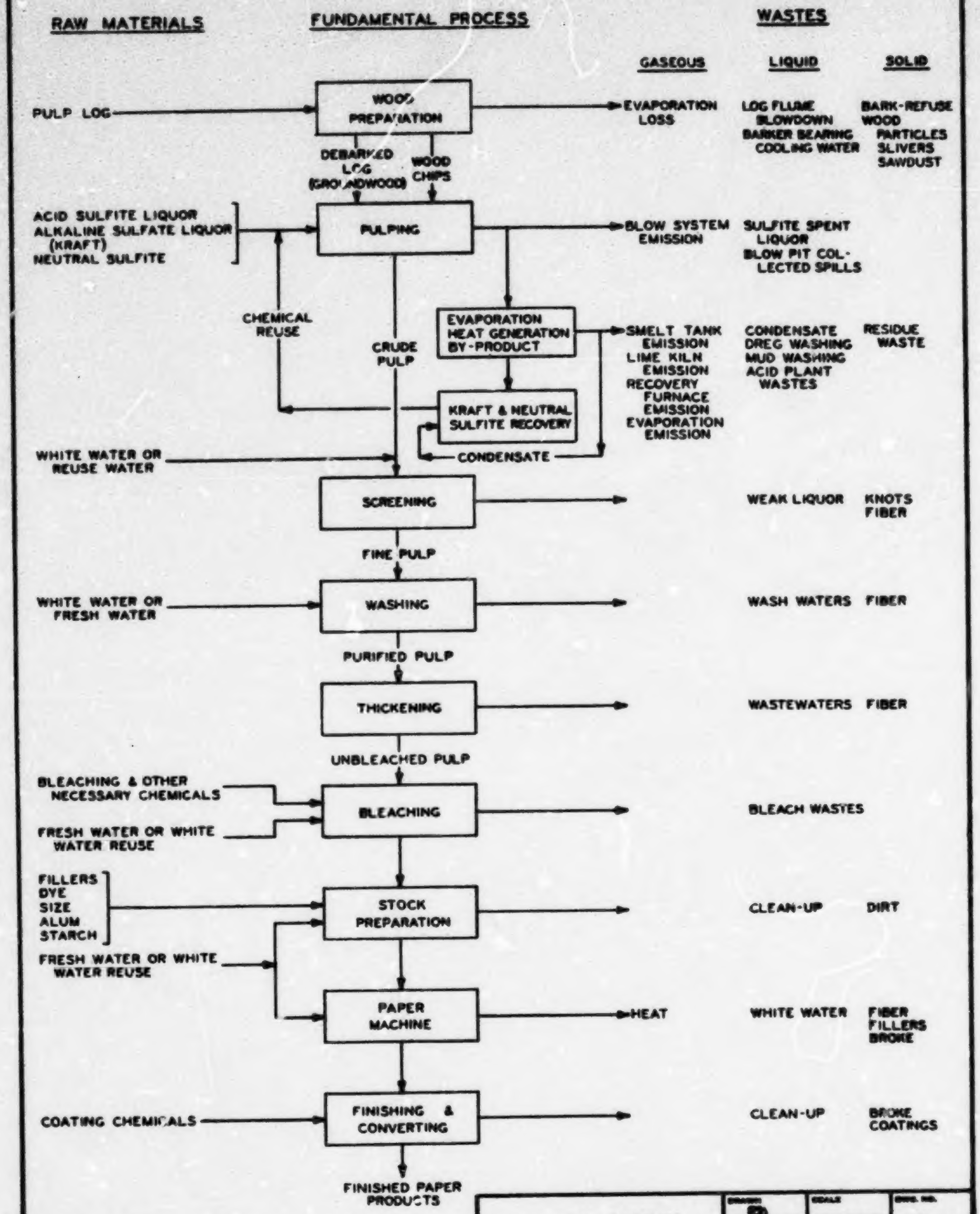
		Bleached Sulfite								
ewer		Older			Present			Newer		
dium	Large	Small	Medium	Large	Small	Medium	Large	Small	Medium	Large
0,000	884,000	50,000	119,000	208,000	195,000	665,000	1,074,000	169,000	329,000	613,000
5,000	904,000	56,000	111,000	154,000	239,000	614,000	1,512,000	226,000	360,000	577,000
1,000	446,000	27,000	57,000	90,000	108,000	320,000	645,000	99,000	172,000	299,000
0,000	167,000	10,000	22,000	34,000	40,000	120,000	242,000	37,000	65,000	111,000
1,000	447,000	27,000	58,000	90,000	108,000	320,000	645,000	99,000	172,000	299,000
8,000	.848,000	170,000	367,000	576,000	690,000	2,039,000	4,118,000	630,000	1,098,000	1,899,000
2,200	1,900	3,420	2,450	1,920	1,380	1,360	5,500	4,200	3,140	2,500
4,600	8,9	500	1,200	2,100	2,000	6,700	10,700	1,700	3,300	6,100
5,200	27,10	1,700	3,300	4,600	7,200	18,100	45,400	6,800	10,800	17,300
2,400	4,500	300	600	900	1,100	3,200	6,500	1,000	1,700	3,000
8,400	58,400	43,800	58,400	73,000	58,400	58,400	73,000	58,400	58,400	58,400
6,200	77,500				8,300	25,000	124,500	7,500	17,600	37,700
7,000	315,000				33,600	101,000	506,000	30,700	71,500	153,000
3,300	107,000	10,800	16,000	27,500	22,600	50,600	196,800	19,000	36,000	70,700
7,100	598,400	57,100	79,500	108,100	133,200	263,000	962,900	125,100	199,300	346,200
1.24	1.10	3.12	1.45	1.00	7.30	4.80	3.50	2.30	1.56	1.30

B

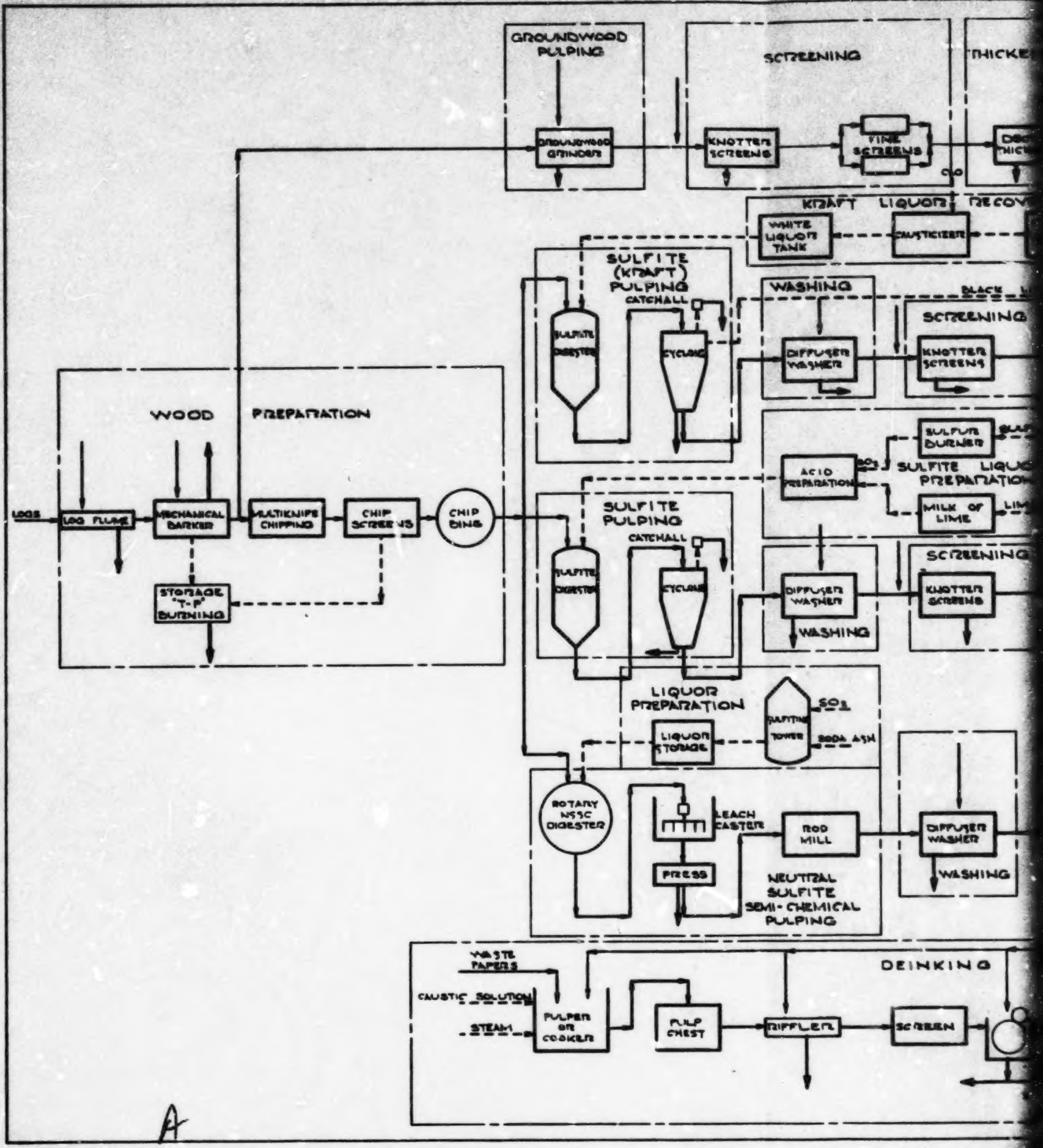
APPENDIX B

F.W.P.C.A. PAPER INDUSTRY PROFILE

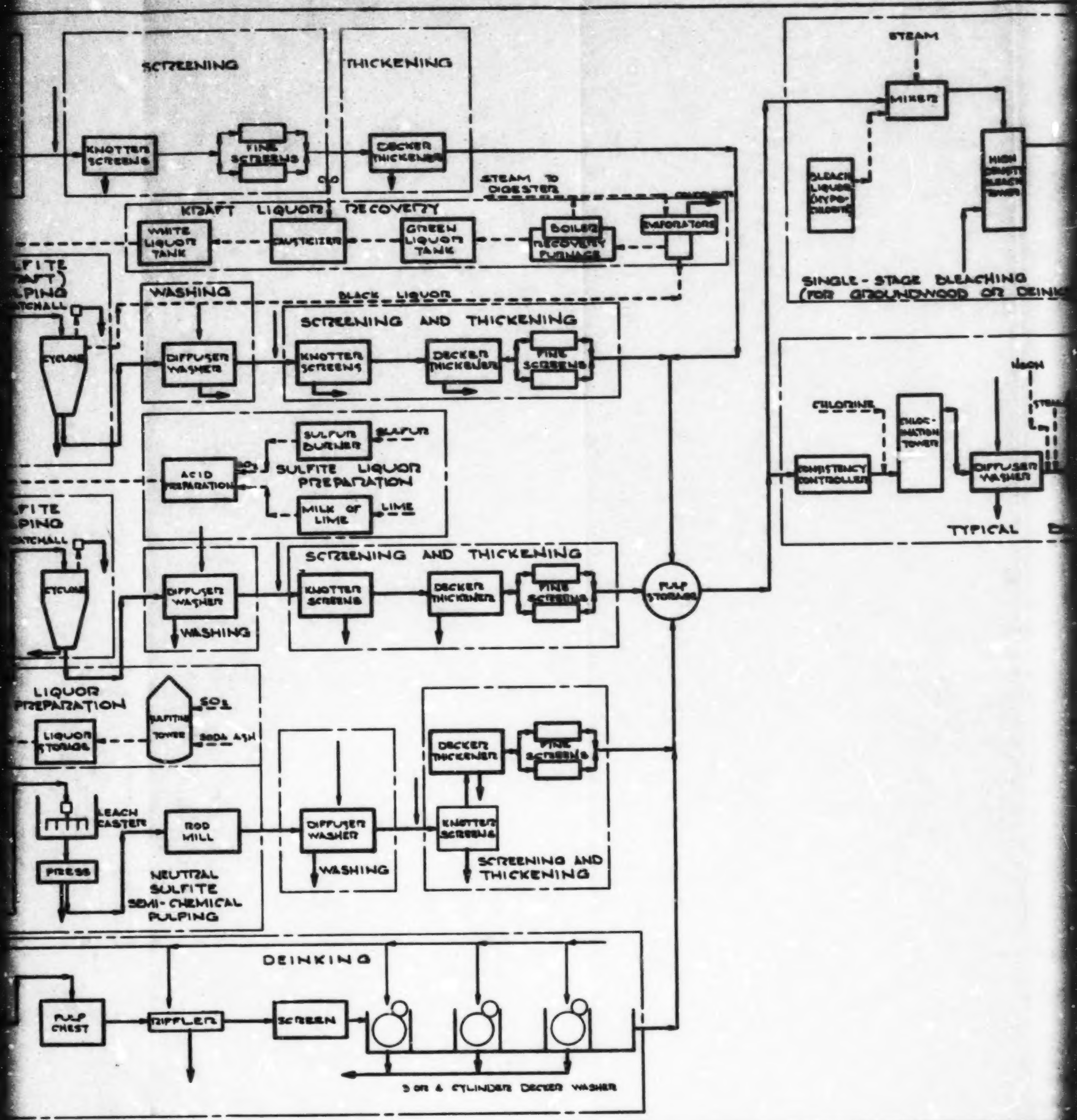
SIMPLIFIED DIAGRAM OF FUNDAMENTAL PULP AND PAPER PROCESSES


RAW MATERIALS
FUNDAMENTAL PROCESS
WASTES
GASEOUS
LIQUID
SOLID
PULP LOG
WOOD PREPARATION
EVAPORATION LOSS
LOG FLUME BLOWDOWN
BARKER BEARING COOLING WATER
BARK-REFUSE
WOOD PARTICLES
SLIVERS
SAWDUST
DEBARKED LOG (GROUNDWOOD)
WOOD CHIPS
ACID SULFITE LIQUOR
ALKALINE SULFATE LIQUOR (KRAFT)
NEUTRAL SULFITE
PULPING
BLOW SYSTEM EMISSION
SULFITE SPENT LIQUOR
BLOW PIT COLLECTED SPILLS
CHEMICAL REUSE
CRUDE PULP
EVAPORATION HEAT GENERATION BY-PRODUCT
SMELT TANK EMISSION
LIME KILN EMISSION
RECOVERY FURNACE EMISSION
EVAPORATION EMISSION
CONDENSATE
DREG WASHING
MUD WASHING
ACID PLANT WASTES
RESIDUE WASTE
KRAFT & NEUTRAL SULFITE RECOVERY
CONDENSATE
WHITE WATER OR REUSE WATER
SCREENING
WEAK LIQUOR
KNOTS
FIBER
FINE PULP
WHITE WATER OR FRESH WATER
WASHING
WASH WATERS
FIBER
PURIFIED PULP
THICKENING
WASTEWATERS
FIBER
UNBLEACHED PULP
BLEACHING & OTHER NECESSARY CHEMICALS
FRESH WATER OR WHITE WATER REUSE
BLEACHING
BLEACH WASTES
FILLERS
DYE
SIZE
ALUM
STARCH
FRESH WATER OR WHITE WATER REUSE
STOCK PREPARATION
CLEAN-UP
DIRT
PAPER MACHINE
HEAT
WHITE WATER
FIBER
FILLERS
BROKE
COATING CHEMICALS
FINISHING & CONVERTING
CLEAN-UP
BROKE
COATINGS
FINISHED PAPER PRODUCTS

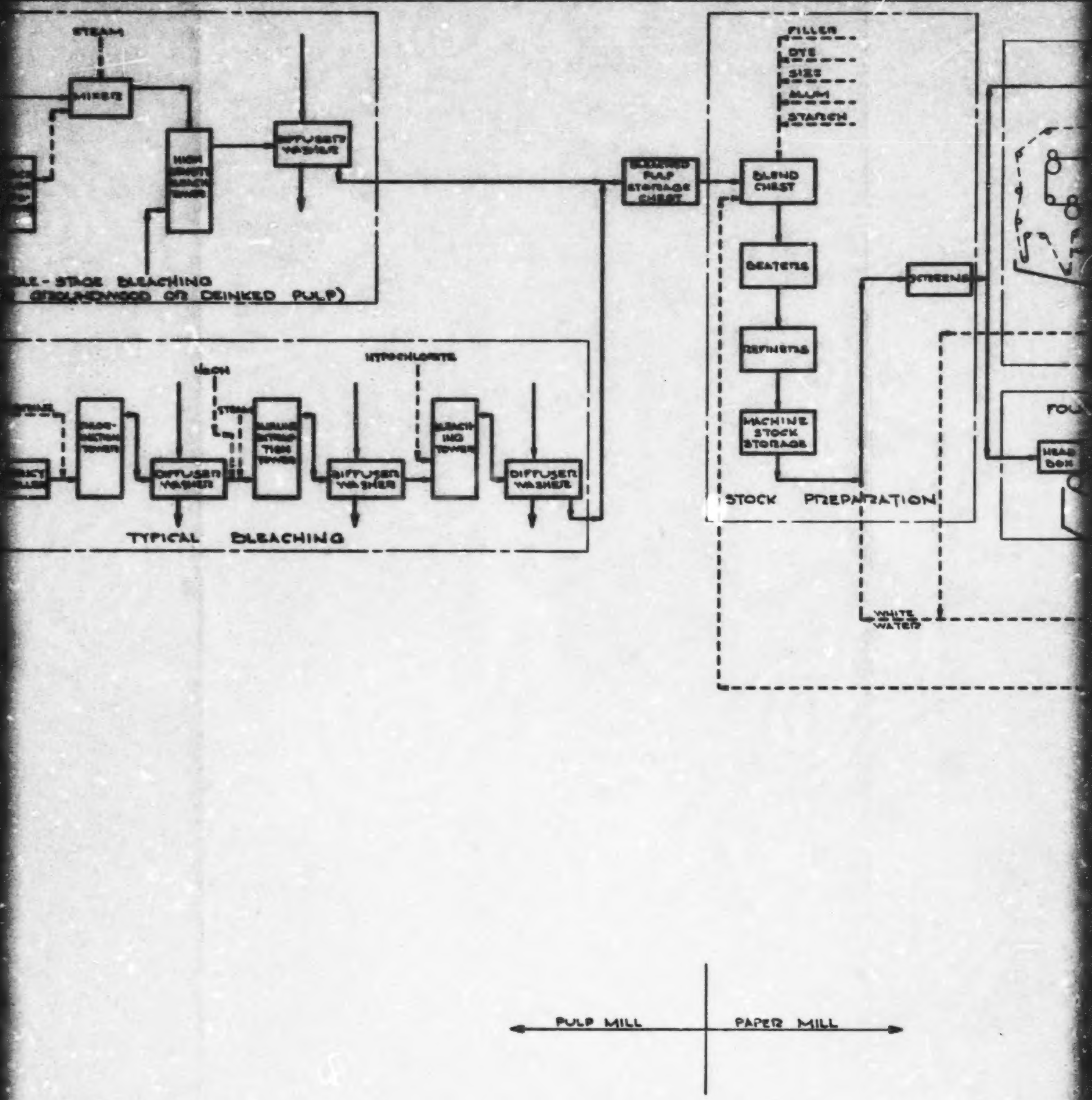
Prepared for F.W.P.C.A.
9-24-67
300-01
B-1


GROUNDWOOD PULPING
GROUNDWOOD GRINDER
SCREENING
KNOTTER SCREENS
FINE SCREENS
THICKE
DECK
THICK
ClO
KRAFT LIQUOR RECOV
WHITE LIQUOR TANK
CAUSTICIZER
SULFITE (KRAFT) PULPING
CATCHALL
SULFITE DIGESTER
CYCLONE
WASHING
BLACK L
SCREENING
DIFFUSER WASHER
KNOTTER SCREENS
WOOD PREPARATION
LOGS
LOG FLUME
MECHANICAL BARKER
MULTIKNIFE CHIPPING
CHIP SCREENS
CHIP BINS
STORAGE "T-P" BURNING
SULFUR BURNER
SULF
ACID PREPARATION
SO2
SULFITE LIQU
PREPARATION
MILK OF LIME
LIM
SULFITE PULPING
CATCHALL
SULFITE DIGESTER
CYCLONE
DIFFUSER WASHER
WASHING
SCREENING
KNOTTER SCREENS
LIQUOR PREPARATION
SULFITING TOWER
SO2
SODA ASH
LIQUOR STORAGE
ROTARY NSSC DIGESTER
LEACH CASTER
PRESS
ROD MILL
NEUTRAL SULFITE SEMI-CHEMICAL PULPING
DIFFUSER WASHER
WASHING
DEINKING
WASTE PAPERS
CAUSTIC SOLUTION
STEAM
PULPER OR COOKER
PULP CHEST
RIFFLER
SCREEN

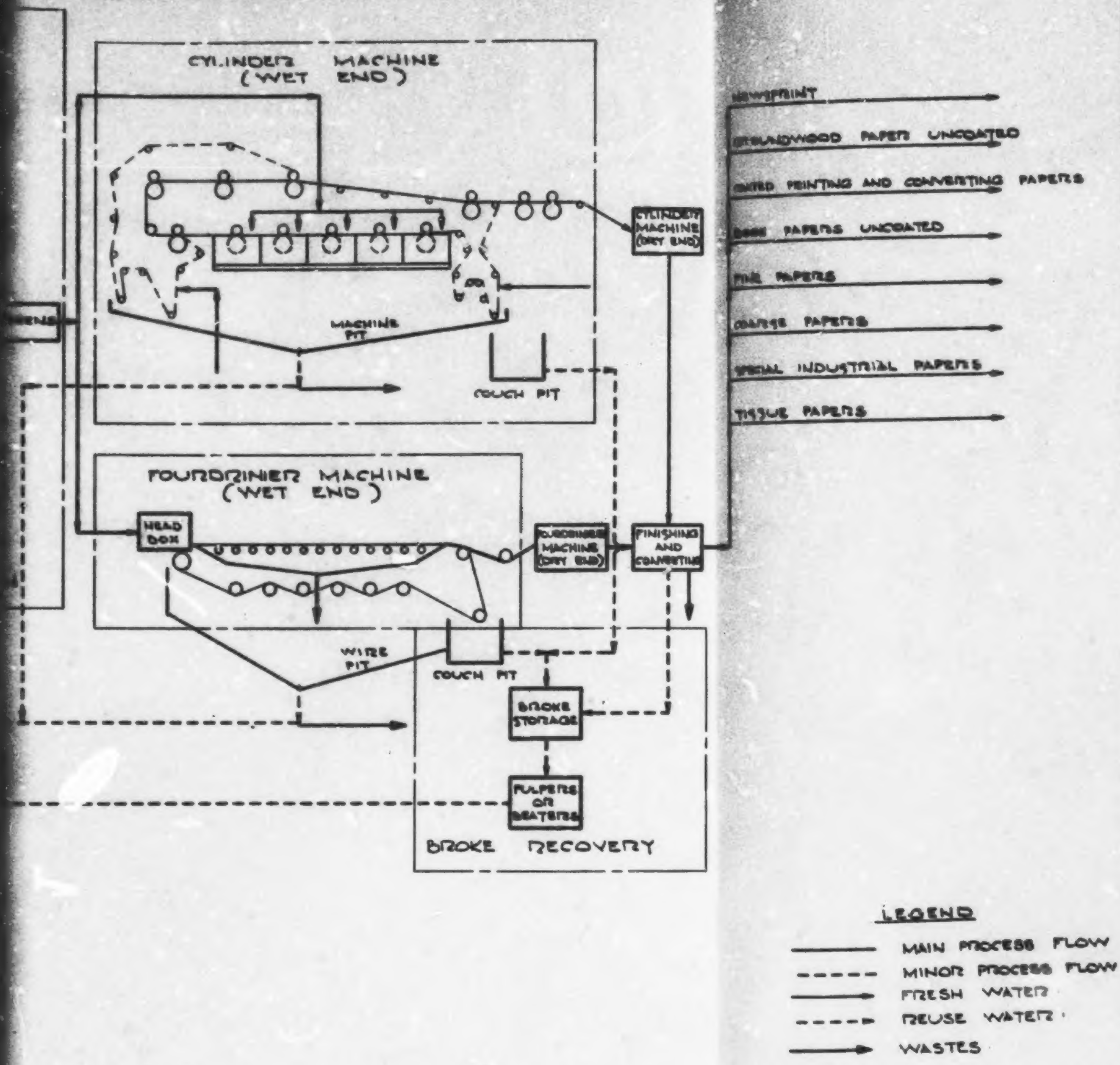
A


SCREENING
THICKENING
KNOTTER SCREENS
FINE SCREENS
DECKER THICKENER
STEAM TO DIGESTER
KRAFT LIQUOR RECOVERY
WHITE LIQUOR TANK
CAUSTICIZER
GREEN LIQUOR TANK
BOILER
RECOVERY FURNACE
EVAPORATORS
CONDENSATE
BLACK LIQUOR
LFITE
RAFT)
LPING
TCHALL
CYCLONE
WASHING
DIFFUSER WASHER
SCREENING AND THICKENING
KNOTTER SCREENS
DECKER THICKENER
FINE SCREENS
SULFUR BURNER
SULFUR
ACID PREPARATION
SO_2
SULFITE LIQUOR PREPARATION
MILK OF LIME
LIME
LFITE
LPING
TCHALL
CYCLONE
DIFFUSER WASHER
WASHING
SCREENING AND THICKENING
KNOTTER SCREENS
DECKER THICKENER
FINE SCREENS
PULP STORAGE
LIQUOR PREPARATION
SULFITING TOWER
SO_2
SODA ASH
LIQUOR STORAGE
LEACH CASTER
ROD MILL
PRESS
NEUTRAL SULFITE SEMI-CHEMICAL PULPING
DIFFUSER WASHER
WASHING
DECKER THICKENER
FINE SCREENS
KNOTTER SCREENS
SCREENING AND THICKENING
DEINKING
PULP CHEST
RIFFLER
SCREEN
3 OR 4 CYLINDER DECKER WASHER
STEAM
MIXER
BLEACH LIQUOR (HYPO-CHLORITE)
HIGH DENSITY BLEACH TOWER
SINGLE-STAGE BLEACHING
(FOR GROUNDWOOD OR DEINK
NaOH
STEAM
CHLORINE
CHLORINATION TOWER
CONSISTENCY CONTROLLER
DIFFUSER WASHER
TYPICAL

B


STEAM
MIXER
HIGH
DIFFUSER WASHER
BLEACHED PULP STORAGE CHEST
-LE - STAGE BLEACHING
GROUNDWOOD OR DEINKED PULP)
NaOH
HYPOCHLORITE
STEAM
TOWER
DIFFUSER WASHER
TION TOWER
DIFFUSER WASHER
BLEACH ING TOWER
DIFFUSER WASHER
TYPICAL BLEACHING
FILLER
DYE
SIZE
ALUM
STARCH
BLEND CHEST
BEATERS
REFINERS
MACHINE STOCK STORAGE
SCREENS
STOCK PREPARATION
HEAD BOX
FOU
WHITE WATER
PULP MILL
PAPER MILL

C

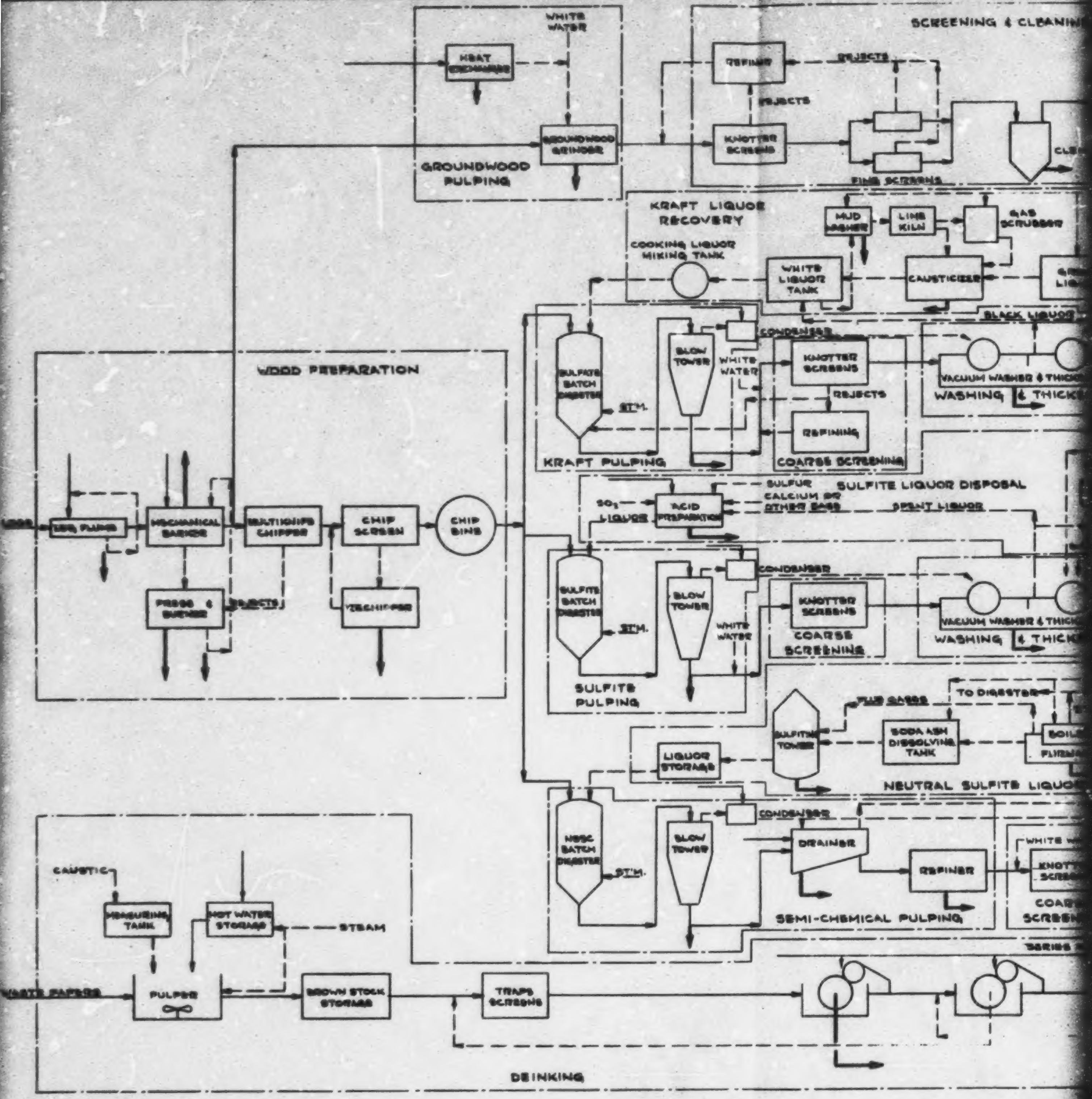

CYLINDER MACHINE (WET END)
MACHINE PIT
COUCH PIT
CYLINDER MACHINE (DRY END)
NEWSPRINT
GROUNDWOOD PAPER UNCOATED
COATED PRINTING AND CONVERTING PAPERS
BOOK PAPERS UNCOATED
FINE PAPERS
COARSE PAPERS
SPECIAL INDUSTRIAL PAPERS
TISSUE PAPERS
FOURDRINIER MACHINE (WET END)
HEAD BOX
FOURDRINIER MACHINE (DRY END)
FINISHING AND CONVERTING
WIRE PIT
COUCH PIT
BROKE STORAGE
PULPERS OR BEATERS
BROKE RECOVERY
LEGEND
MAIN PROCESS FLOW
MINOR PROCESS FLOW
FRESH WATER
REUSE WATER
WASTES

F.W.P.C.A. PAPER INDUSTRY PROFILE

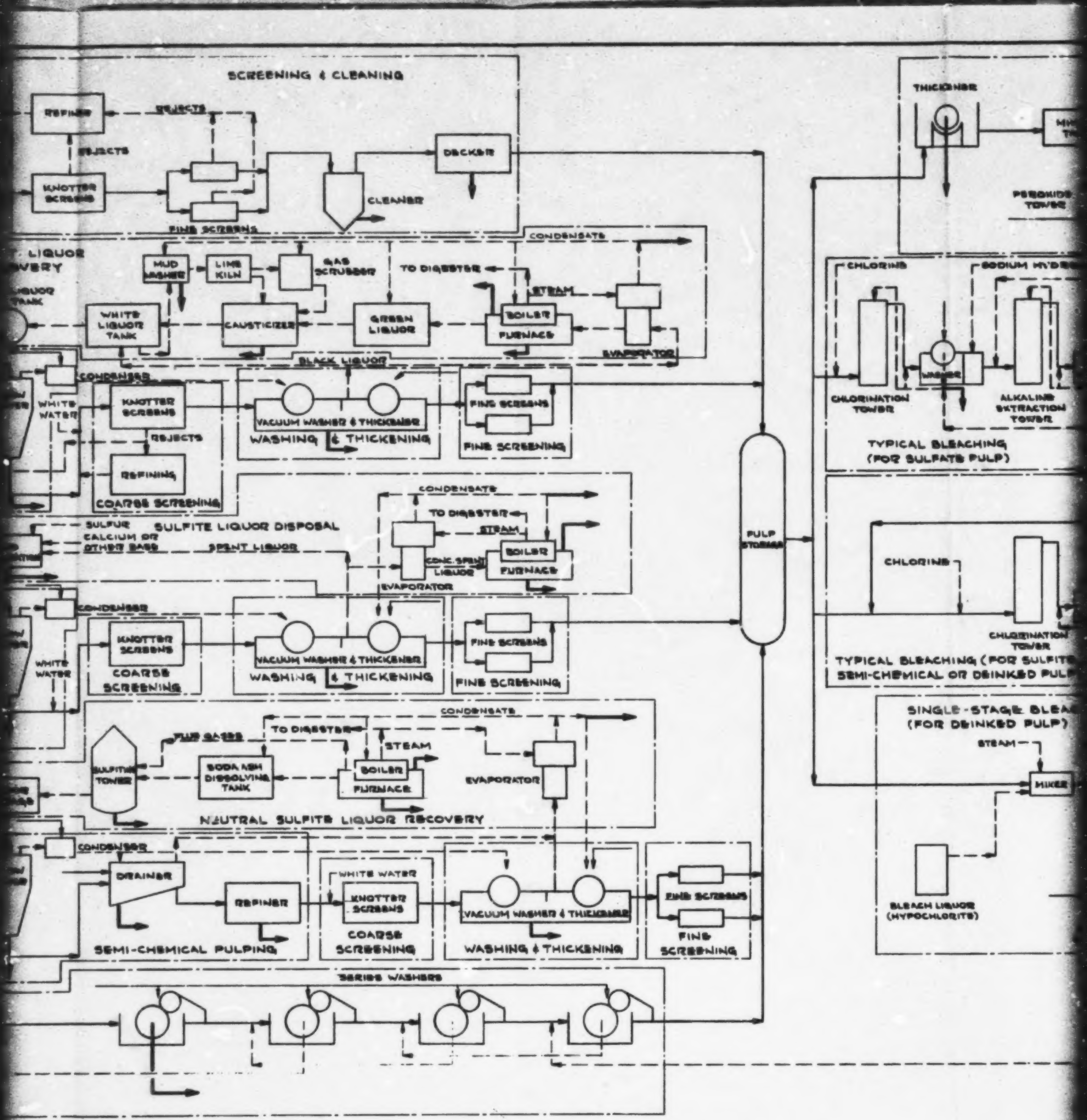
SUBPROCESS SERIES REPRESENTATIVE OF OLDER TECHNOLOGY

Prepared for F.W.P.C.A.	DRAWN GB	SCALE	DWG. NO. B-2
	DATE 9-26-67	W.O. NO. 300-01	

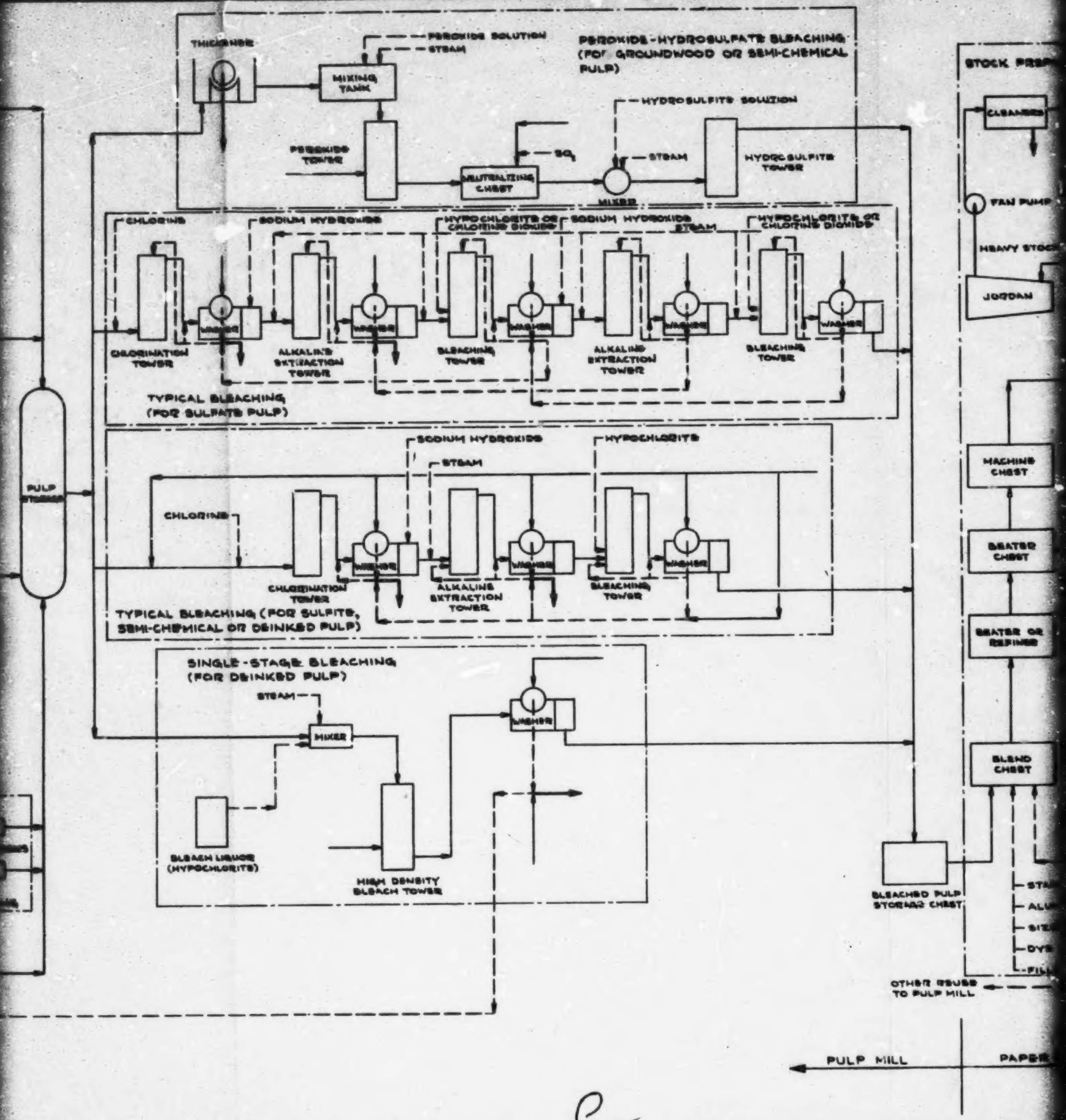
D

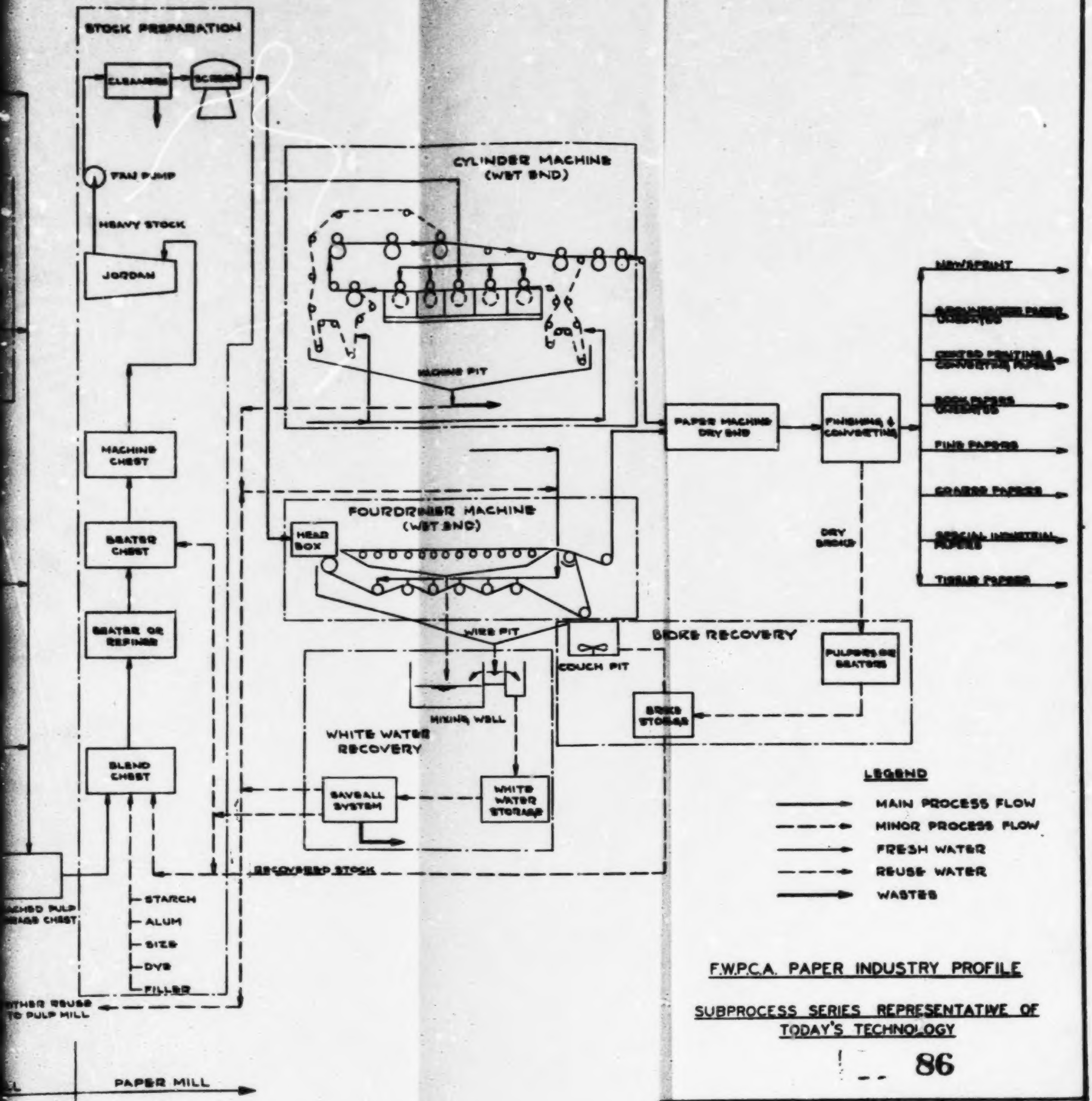

WHITE WATER
HEAT EXCHANGER
GROUNDWOOD GRINDER
GROUNDWOOD PULPING
SCREENING & CLEANIN
REFINER
REJECTS
KNOTTER SCREENS
FINE SCREENS
KRAFT LIQUOR RECOVERY
COOKING LIQUOR MIXING TANK
MUD WASHER
LIME KILN
GAS SCRUBBER
WHITE LIQUOR TANK
CAUSTICIZER
BLACK LIQUOR
CONDENSER
SULFATE BATCH DIGESTER
ST'M.
BLOW TOWER
WHITE WATER
KNOTTER SCREENS
REJECTS
REFINING
KRAFT PULPING
COARSE SCREENING
VACUUM WASHER & THICK
WASHING & THICK
WOOD PREPARATION
WOOD
LOG FLUME
MECHANICAL BARKER
MULTIKNIFE CHIPPER
CHIP SCREEN
CHIP BINS
PRESS & BURNER
REJECTS
RECHIPPER
SULFUR
CALCIUM OR OTHER BASE
SULFITE LIQUOR DISPOSAL
SPENT LIQUOR
SO₂
LIQUOR
ACID PREPARATION
CONDENSER
SULFITE BATCH DIGESTER
ST'M.
BLOW TOWER
WHITE WATER
KNOTTER SCREENS
COARSE SCREENING
VACUUM WASHER & THICK
WASHING & THICK
SULFITE PULPING
TO DIGESTER
FLUE GASES
SULFITING TOWER
SODA ASH DISSOLVING TANK
BOIL
FURNA
LIQUOR STORAGE
NEUTRAL SULFITE LIQUO
CONDENSER
NSSC BATCH DIGESTER
ST'M.
BLOW TOWER
DRAINER
REFINER
WHITE W
KNOTT SCREE
COAR SCREEN
SEMI-CHEMICAL PULPING
SERIES
CAUSTIC
MEASURING TANK
HOT WATER STORAGE
STEAM
WASTE PAPERS
PULPER
BROWN STOCK STORAGE
TRAPS SCREENS
DEINKING

A


SCREENING & CLEANING
REFINER
REJECTS
REJECTS
KNOTTER SCREENS
FINE SCREENS
CLEANER
DECKER
LIQUOR
VERY
LIQUOR TANK
MUD WASHER
LIME KILN
GAS SCRUBBER
CONDENSATE
TO DIGESTER
STEAM
WHITE LIQUOR TANK
CAUSTICIZER
GREEN LIQUOR
BOILER
FURNACE
EVAPORATOR
BLACK LIQUOR
CONDENSER
WHITE WATER
KNOTTER SCREENS
REJECTS
REFINING
COARSE SCREENING
VACUUM WASHER & THICKENER
WASHING & THICKENING
FINE SCREENS
FINE SCREENING
SULFUR
CALCIUM OR OTHER BASE
SULFITE LIQUOR DISPOSAL
SPENT LIQUOR
CONDENSATE
TO DIGESTER
STEAM
CONC. SPENT LIQUOR
BOILER
FURNACE
EVAPORATOR
CONDENSER
WHITE WATER
KNOTTER SCREENS
COARSE SCREENING
VACUUM WASHER & THICKENER
WASHING & THICKENING
FINE SCREENS
FINE SCREENING
CONDENSATE
TO DIGESTER
STEAM
FLUE GASES
SULFITE TOWER
SODA ASH DISSOLVING TANK
BOILER
FURNACE
EVAPORATOR
NEUTRAL SULFITE LIQUOR RECOVERY
CONDENSER
DRAINER
REFINER
SEMI-CHEMICAL PULPING
WHITE WATER
KNOTTER SCREENS
COARSE SCREENING
VACUUM WASHER & THICKENER
WASHING & THICKENING
FINE SCREENS
FINE SCREENING
SERIES WASHERS
PULP STORAGE
THICKENER
PEROXIDE TOWER
CHLORINE
SODIUM HYDR
CHLORINATION TOWER
WASHER
ALKALINE EXTRACTION TOWER
TYPICAL BLEACHING (FOR SULFATE PULP)
CHLORINE
CHLORINATION TOWER
TYPICAL BLEACHING (FOR SULFITE SEMI-CHEMICAL OR DEINKED PUL
SINGLE-STAGE BLEA
(FOR DEINKED PULP)
STEAM
MIXER
BLEACH LIQUOR (HYPOCHLORITE)

B


THICKENER
PEROXIDE SOLUTION
STEAM
MIXING TANK
PEROXIDE-HYDROSULFITE BLEACHING (FOR GROUNDWOOD OR SEMI-CHEMICAL PULP)
HYDROSULFITE SOLUTION
PEROXIDE TOWER
SO_2
STEAM
NEUTRALIZING CHEST
MIXER
HYDROSULFITE TOWER
CHLORINE
SODIUM HYDROXIDE
HYPOCHLORITE OR CHLORINE DIOXIDE
SODIUM HYDROXIDE
STEAM
HYPOCHLORITE OR CHLORINE DIOXIDE
WASHER
CHLORINATION TOWER
ALKALINE EXTRACTION TOWER
BLEACHING TOWER
ALKALINE EXTRACTION TOWER
BLEACHING TOWER
TYPICAL BLEACHING (FOR SULFATE PULP)
PULP STORAGE
SODIUM HYDROXIDE
STEAM
HYPOCHLORITE
CHLORINE
WASHER
CHLORINATION TOWER
ALKALINE EXTRACTION TOWER
BLEACHING TOWER
TYPICAL BLEACHING (FOR SULFITE, SEMI-CHEMICAL OR DEINKED PULP)
SINGLE-STAGE BLEACHING (FOR DEINKED PULP)
STEAM
MIXER
WASHER
BLEACH LIQUOR (HYPOCHLORITE)
HIGH DENSITY BLEACH TOWER
STOCK PREP
CLEANERS
FAN PUMP
HEAVY STOCK
JORDAN
MACHINE CHEST
BEATER CHEST
BEATER OR REFINER
BLEND CHEST
BLEACHED PULP STORAGE CHEST
STA
ALU
SIZ
DYE
FIL
OTHER REUSE TO PULP MILL
PULP MILL
PAPER


STOCK PREPARATION
CLEANERS
SCREENS
FAN PUMP
HEAVY STOCK
JORDAN
MACHINE CHEST
BEATER CHEST
BEATER OR REFINER
BLEND CHEST
STARCH
ALUM
SIZE
DYE
FILLER
ACHED PULP
RAGE CHEST
THER REUSE
TO PULP MILL
PAPER MILL
CYLINDER MACHINE
(WET END)
MACHINE PIT
FOURDRINIER MACHINE
(WET END)
HEAD BOX
WIRE PIT
COUCH PIT
MIXING WELL
WHITE WATER RECOVERY
SAVEALL SYSTEM
WHITE WATER STORAGE
RECOVERED STOCK
BROKE RECOVERY
PULPERS OR BEATERS
BROKE STORAGE
DRY BROKE
PAPER MACHINE DRY END
FINISHING & CONVERTING
NEWSPRINT
GROUNDWOOD PAPER UNCOATED
COATED PRINTING & CONVERTING PAPERS
BOOK PAPERS UNCOATED
FINE PAPERS
COARSE PAPERS
SPECIAL INDUSTRIAL PAPERS
TISSUE PAPERS
LEGEND
MAIN PROCESS FLOW
MINOR PROCESS FLOW
FRESH WATER
REUSE WATER
WASTES

F.W.P.C.A. PAPER INDUSTRY PROFILE

SUBPROCESS SERIES REPRESENTATIVE OF
TODAY'S TECHNOLOGY

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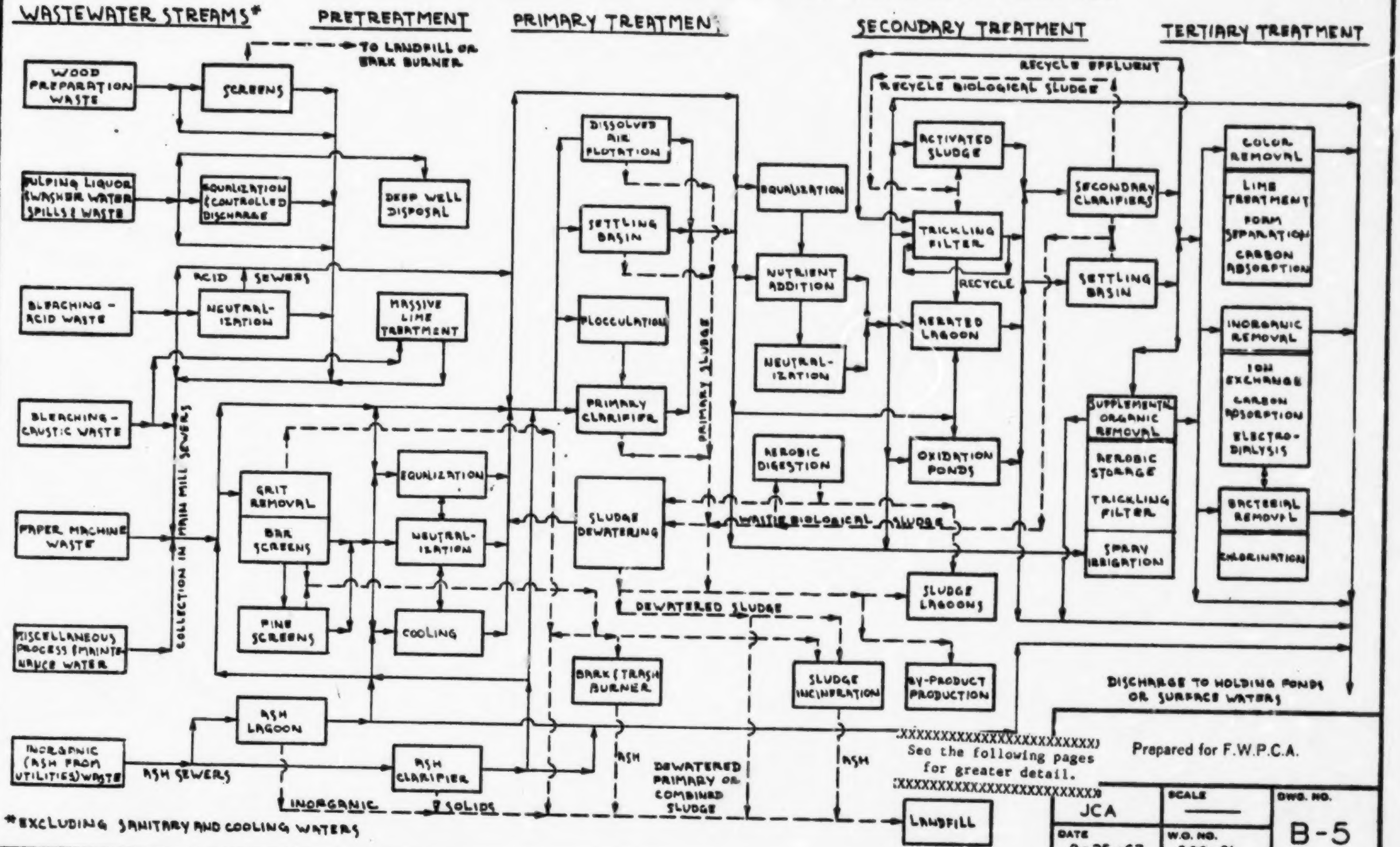
F.W.P.C.A. PAPER INDUSTRY PROFILE
SEQUENCE AND ALTERNATIVES IN WASTEWATER TREATMENT PRACTICES


WASTEWATER STREAMS*
PRETREATMENT
PRIMARY TREATMENT
SECONDARY TREATMENT
TERTIARY TREATMENT
WOOD PREPARATION WASTE
PULPING LIQUOR (WASHER WATER SPILLS) WASTE
BLEACHING - ACID WASTE
BLEACHING - CAUSTIC WASTE
PAPER MACHINE WASTE
MISCELLANEOUS PROCESS (MAINTENANCE WATER
INORGANIC (ASH FROM UTILITIES) WASTE
SCREENS
TO LANDFILL OR BARK BURNER
EQUALIZATION (CONTROLLED DISCHARGE
DEEP WELL DISPOSAL
ACID SEWERS
NEUTRALIZATION
MASSIVE LIME TREATMENT
COLLECTION IN MAIN MILL SEWERS
GRIT REMOVAL
BAR SCREENS
FINE SCREENS
EQUALIZATION
NEUTRALIZATION
COOLING
ASH LAGOON
ASH SEWERS
ASH CLARIFIER
INORGANIC
SOLIDS
DISSOLVED AIR FLOTATION
SETTLING BASIN
FLOCCULATION
PRIMARY CLARIFIER
PRIMARY SLUDGE
SLUDGE DEWATERING
DEWATERED SLUDGE
BARK (TRASH BURNER
ASH
DEWATERED PRIMARY OR COMBINED SLUDGE
EQUALIZATION
NUTRIENT ADDITION
NEUTRALIZATION
AEROBIC DIGESTION
WASTE BIOLOGICAL SLUDGE
SLUDGE INCINERATION
ASH
RECYCLE EFFLUENT
RECYCLE BIOLOGICAL SLUDGE
ACTIVATED SLUDGE
TRICKLING FILTER
RECYCLE
AERATED LAGOON
OXIDATION PONDS
SLUDGE LAGOONS
BY-PRODUCT PRODUCTION
LANDFILL
SECONDARY CLARIFIERS
SETTLING BASIN
SUPPLEMENTAL ORGANIC REMOVAL
AEROBIC STORAGE
TRICKLING FILTER
SPRAY IRRIGATION
COLOR REMOVAL
LIME TREATMENT
FOAM SEPARATION
CARBON ABSORPTION
INORGANIC REMOVAL
ION EXCHANGE
CARBON ADSORPTION
ELECTRO-DIALYSIS
BACTERIAL REMOVAL
CHLORINATION
DISCHARGE TO HOLDING PONDS OR SURFACE WATERS

*EXCLUDING SANITARY AND COOLING WATERS

XXXXXXXXXXXXXXXXXXXXXXXXX
See the following pages
for greater detail.
XXXXXXXXXXXXXXXXXXXXXXXXX

Prepared for F.W.P.C.A.

	SCALE	DWG. NO.
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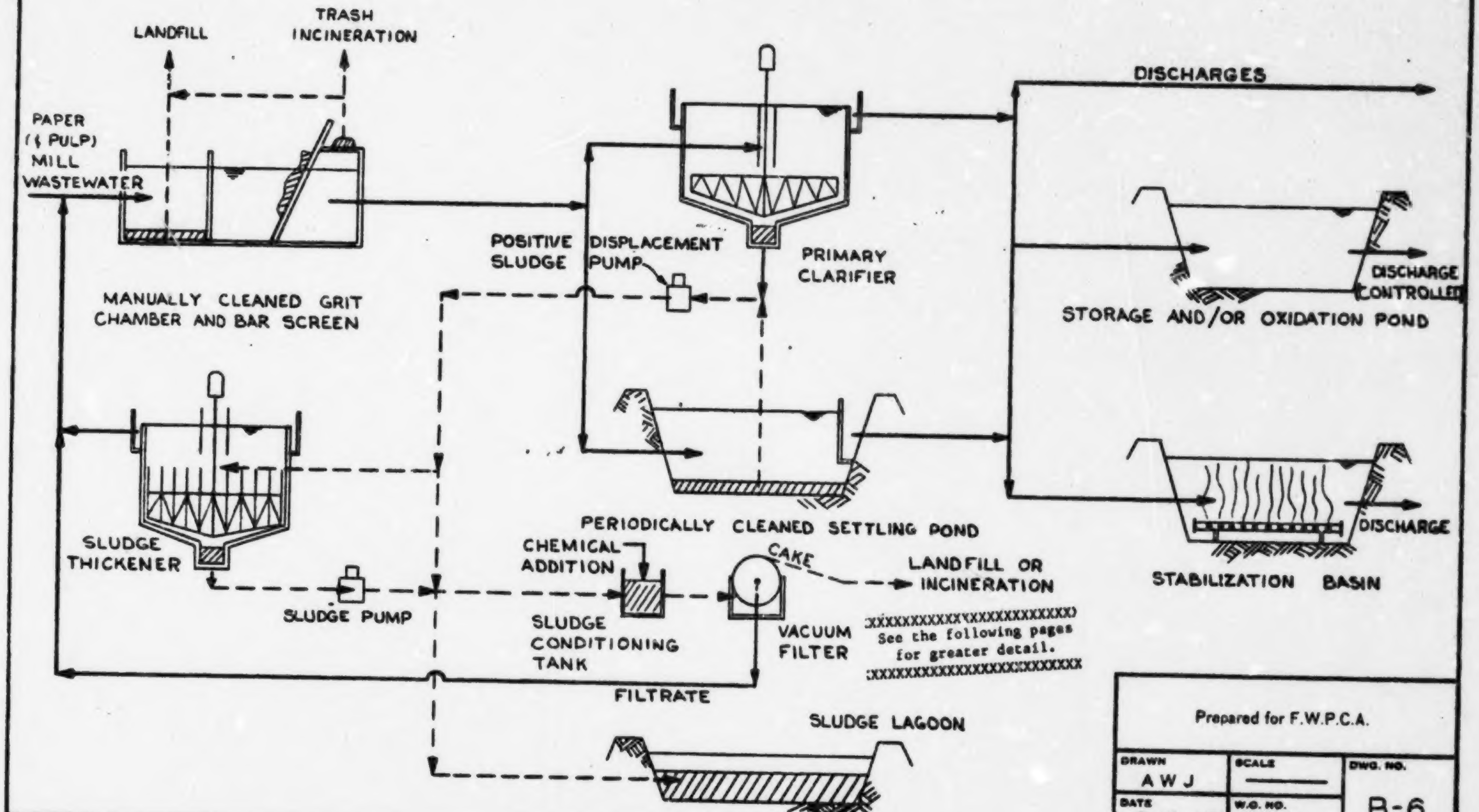
DATE 9-25-67	W.O. NO. 300-01	

F.W.P.C.A. PAPER INDUSTRY PROFILE - WASTEWATER TREATMENT PRACTICE
OLDER TECHNOLOGY


LANDFILL
TRASH INCINERATION
PAPER (& PULP) MILL WASTEWATER
MANUALLY CLEANED GRIT CHAMBER AND BAR SCREEN
POSITIVE DISPLACEMENT PUMP
SLUDGE
PRIMARY CLARIFIER
DISCHARGES
STORAGE AND/OR OXIDATION POND
DISCHARGE CONTROLLED
PERIODICALLY CLEANED SETTLING POND
SLUDGE THICKENER
SLUDGE PUMP
CHEMICAL ADDITION
SLUDGE CONDITIONING TANK
CAKE
LANDFILL OR INCINERATION
VACUUM FILTER
FILTRATE
STABILIZATION BASIN
DISCHARGE
SLUDGE LAGOON

XXXXXXXXXXXXXXXXXXXXXXXX
See the following pages
for greater detail.
XXXXXXXXXXXXXXXXXXXXXXXX

Prepared for F.W.P.C.A.

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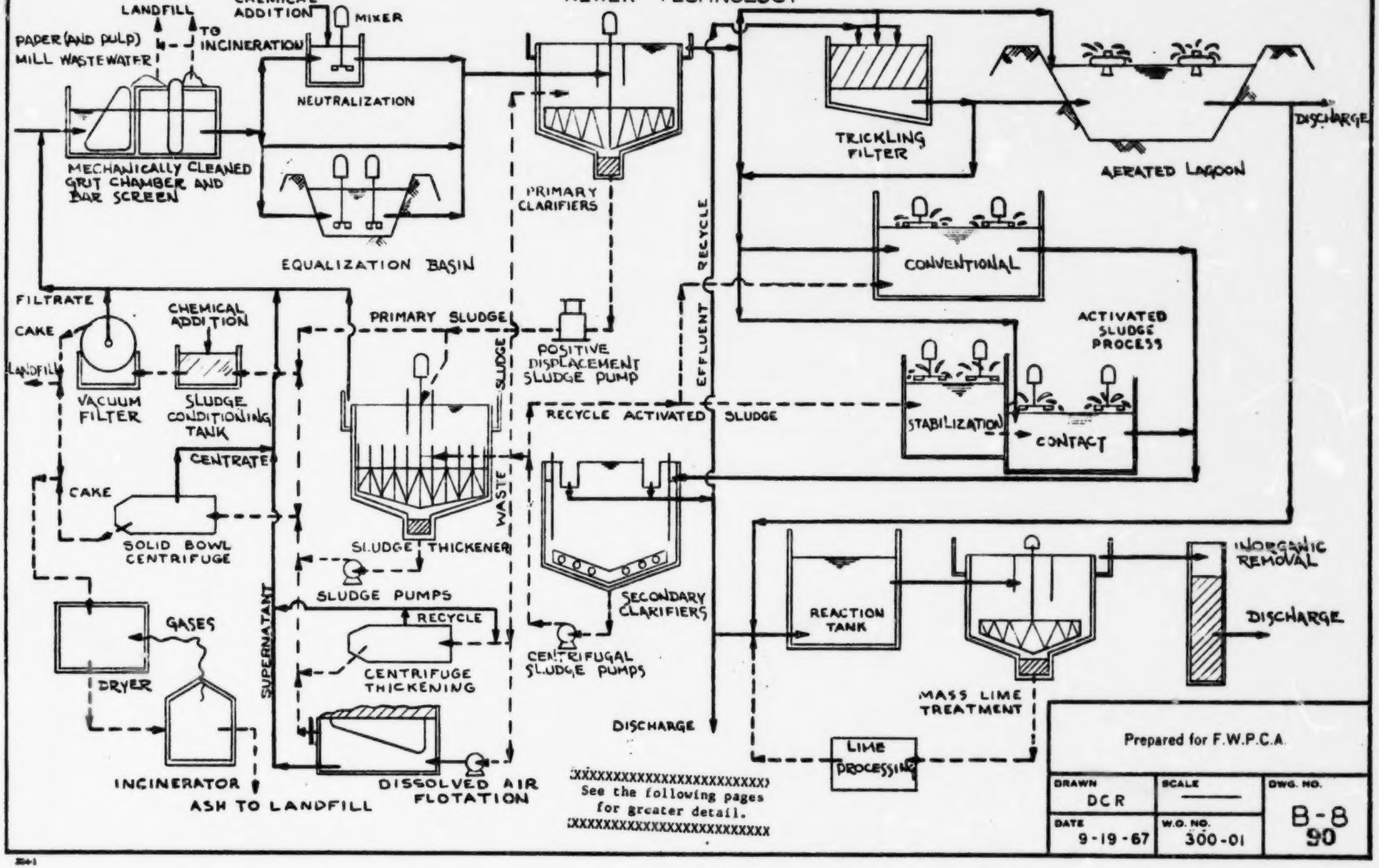
DATE 9-19-67	W.O. NO. 300-01	

F.W.P.C.A. PAPER INDUSTRY PROFILE - WASTEWATER TREATMENT PRACTICE

NEWER TECHNOLOGY


LANDFILL
TO INCINERATION
CHEMICAL ADDITION
MIXER
PAPER (AND PULP) MILL WASTEWATER
NEUTRALIZATION
MECHANICALLY CLEANED GRIT CHAMBER AND BAR SCREEN
EQUALIZATION BASIN
PRIMARY CLARIFIERS
TRICKLING FILTER
AERATED LAGOON
DISCHARGE
RECYCLE
EFFLUENT
CONVENTIONAL
ACTIVATED SLUDGE PROCESS
STABILIZATION
CONTACT
FILTRATE
CAKE
LANDFILL
CHEMICAL ADDITION
VACUUM FILTER
SLUDGE CONDITIONING TANK
PRIMARY SLUDGE
SLUDGE
POSITIVE DISPLACEMENT SLUDGE PUMP
RECYCLE ACTIVATED SLUDGE
CENTRATE
CAKE
SOLID BOWL CENTRIFUGE
WASTE
SLUDGE THICKENER
SLUDGE PUMPS
SECONDARY CLARIFIERS
CENTRIFUGAL SLUDGE PUMPS
RECYCLE
CENTRIFUGE THICKENING
GASES
DRYER
SUPERNATANT
INCINERATOR
ASH TO LANDFILL
DISSOLVED AIR FLOTATION
DISCHARGE
REACTION TANK
MASS LIME TREATMENT
INORGANIC REMOVAL
DISCHARGE
LIME PROCESSING

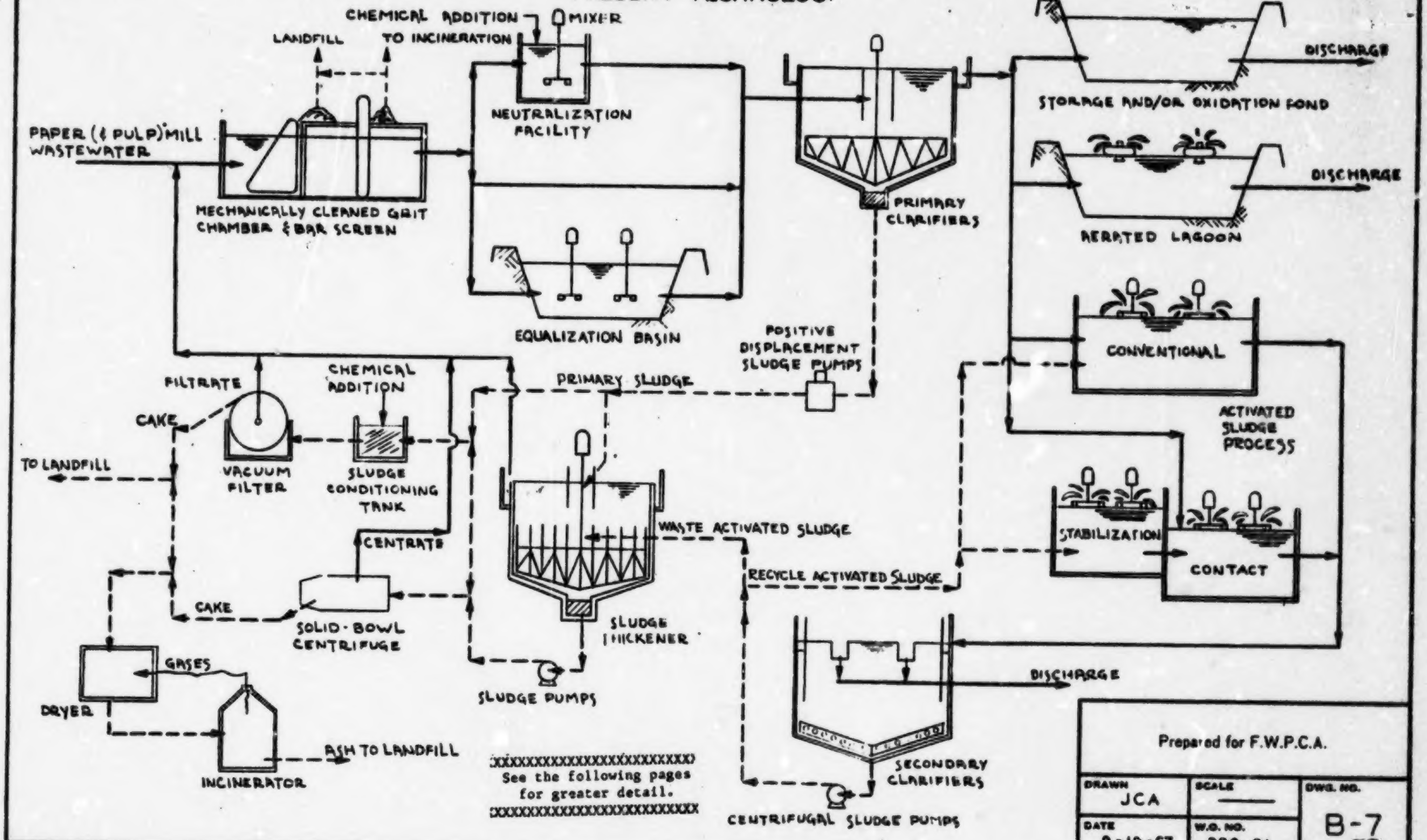
XXXXXXXXXXXXXXXXXXXXXXXXXX
See the following pages
for greater detail.
XXXXXXXXXXXXXXXXXXXXXXXXXX

Prepared for F.W.P.C.A.

DRAWN	SCALE	DWG. NO.
DCR	—	B-8
DATE	W.O. NO.	
9-19-67	300-01	90

F.W.P.C.A. PAPER INDUSTRY PROFILE - WASTEWATER TREATMENT PRACTICE

PRESENT TECHNOLOGY


CHEMICAL ADDITION
MIXER
LANDFILL
TO INCINERATION
NEUTRALIZATION FACILITY
PAPER (& PULP) MILL WASTEWATER
MECHANICALLY CLEANED GRIT CHAMBER & BAR SCREEN
EQUALIZATION BASIN
PRIMARY CLARIFIERS
STORAGE AND/OR OXIDATION POND
DISCHARGE
AERATED LAGOON
DISCHARGE
CONVENTIONAL
ACTIVATED SLUDGE PROCESS
STABILIZATION
CONTACT
POSITIVE DISPLACEMENT SLUDGE PUMPS
PRIMARY SLUDGE
FILTRATE
CHEMICAL ADDITION
CAKE
TO LANDFILL
VACUUM FILTER
SLUDGE CONDITIONING TANK
CENTRATE
WASTE ACTIVATED SLUDGE
RECYCLE ACTIVATED SLUDGE
CAKE
SOLID-BOWL CENTRIFUGE
SLUDGE THICKENER
SLUDGE PUMPS
GASES
DRYER
INCINERATOR
ASH TO LANDFILL
DISCHARGE
SECONDARY CLARIFIERS
CENTRIFUGAL SLUDGE PUMPS

XXXXXXXXXXXXXXXXXXXXXXXXXX
See the following pages
for greater detail.
XXXXXXXXXXXXXXXXXXXXXXXXXX

Prepared for F.W.P.C.A.

DRAWN JCA	SCALE ——	DWG. NO. B-7
DATE 9-19-67	W.O. NO. 300-01	

APPENDIX C

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APPENDIX D

APPENDIX D

FUNDAMENTAL PROCESSES AND SUBPROCESSES PULP AND PAPER INDUSTRY

Definition of Fundamental Manufacturing Processes

The Profile for Paper Mills (except buildings) is to include pulp mills directly associated with paper mills (integrated pulp and paper mills). Because pulp mills are to be discussed in the fundamental process description, it was considered advantageous to discuss an integrated pulp and paper mill rather than to discuss them separately.

An integrated pulp and paper mill can be divided into two basic parts: 1) a pulp mill which includes the fundamental processes of wood preparation, pulping, screening, washing, thickening, and bleaching; and 2) the paper mill which includes stock preparation, paper machine, and converting and finishing. A simplified diagram of the fundamental processes for the pulp and paper industry is shown in Drawing No. 1. Also shown in the drawing are the raw materials used, final products obtained, and the wastes generated in the form of liquids, gases, and solids. Individual fundamental manufacturing processes are described in the following sections.

Wood Preparation

Wood preparation is classified as a fundamental process although it is actually a group of operations which are necessary to prepare the log for the digester. Basically, the process includes the transportation of the log from storage to debarking facilities, debarking, chipping, chip screening, and chip storage.

Log Transportation

Wood logs to be used in the pulping operation are stored in piles, ponds or rivers depending on the mill site. When the logs are stored in piles, periodical dampening is required to control spontaneous combustion.

Transportation of the logs from storage to debarking facilities is a two-step operation: using a crane, the logs are first removed from the storage area to a conveyer, and then transported to the debarking drums by log flumes or a conveyer system. Ordinarily, the log flume is equipped with a log pond where the log is retained and soaked before being placed in the flume. In many mills, the log movement through the flume is assisted by currents artificially created by paddle wheels, propellers, or pumps. Tremendous amounts of wastewater are generated both in the log ponds and flumes; however, much of it can be reused if grit chambers and fine screens are provided in the recycle line to effect removal of the grit and bark.

Debarking

At the debarking facilities, the log is picked up from the flume by a lift conveyer and fed into the debarker where the bark is removed from the log. Log debarking is necessary in order to insure that the pulp will be free from dirt specks, particles of bark and other objectionable matter. The three principal types of bark removal operations are mechanical, hydraulic, and chemical.

1. Mechanical debarking uses cutting or friction imparted by a rotating action plus water which assists in loosening the bark from the log. At the point of discharge, the logs which have not been completely debarked are returned to the beginning of the cycle for further treatment. Typical machines used are rotating cylindrical drums and stationary friction barkers. The rotating cylindrical drum is commonly used in medium and large size mills, while the use of the stationary friction barker is limited to some small mills. Since the efficiency of mechanical debarking is rather low, the power consumption is very high, and the wood damage is severe, especially for dry wood. Some techniques involving soaking and pretreatment have been practiced in an endeavor to reduce these adverse effects. Methods practiced to increase the efficiency are rinsing with warm water, storage in steam chambers, and the addition of chemicals.

2. Hydraulic debarking uses a hydraulic barker which consists of a jet or jets of high pressure (1,000 psi or more) water directed against a log to fragment and remove the bark. Varying somewhat in details and methods of operation, several variations of this technique are now used in small mills.

3. Chemical debarking is a relatively new process and is accomplished by the introduction of chemicals into the sap stream of the living tree. Various chemicals have been suggested, but the toxic effect

of the solution must be eliminated if this process is to be developed for industry-wide use. Other disadvantages are that the dead tree in the forest tends to become too dry.

4. Long log debarking is a process currently being developed by the industry in which the log is not cut, but is debarked in one piece. When the whole tree-length log is debarked in a unit operation, the costs for logging, transportation, handling, and storage are reduced significantly. Another advantage can be realized through the utilization of the top sections of the trees with log diameters as small as 4 inches. Usually, log sections of this diameter split badly in the drum barkers, and short lengths of this diameter cannot be handled in the mechanical barkers. The application of this debarking technique is increasing each year.

Bark Disposal

Bark which has been removed from the log in the debarking operation presents a major disposal problem in most mills. Acceptable disposal methods include incineration for heat generation, composting, or utilized in by-product recovery facilities. The feasibility of using any one of these methods is dependent on local conditions and the individual species or type of wood from which the bark has been removed.

The utilization of heat from the incineration of bark has much promise, and is particularly economical when used in conjunction with dry debarking operations where no auxiliary dewatering step is required. Although bark emerging from wet dabarking operations needs to be dewatered prior to incineration, a mechanical press can be effective and economical in removing the excess water. Either type of bark can be burned in a separate furnace designed for this type of installation, or burnt in combination with oil, coal, or gas. The heat released from the burning bark is then utilized to generate steam.

Composting for volume reduction is employed by some mills, but the applicability of this disposal method is dependent upon the availability of a large land area. Since many mills do not have sufficient land suitable for bark composting, this method has found limited acceptance.

Chipping

After the log has been debarked, the stripped log is conveyed to the chipping operation where it is fragmented into segments suitably sized to enable the cooking liquor in the digester to penetrate the wood quickly, completely, and uniformly. By mechanical means, chips of about 5/8 to 3/4 inches in size are produced.

One of the most widely accepted method of chipping is with the multiknife-type chipper, which consists of knives attached to a circular disk with a chute to place the log perpendicular to the knives. Care must be exercised to minimize the amount of sawdust and slivers generated while also insuring that the fibers are not damaged by undue compression which would result in a low viscosity and high cellulose degradation in dissolving pulps. Proper control of the speed and sharpness of the knives will insure the production of uniform chips while undesired side effects are kept to a minimum.

Chip Screening

To separate the useful chips from sawdust and slivers, two operations are generally required; mechanical screening (rotary, shaker, and vibratory) and air blast cleaning. During the screening operation, properly sized chips pass through the screen while the oversize chips and slivers remain on the screen until rejected to a conveyer which carries them to a chip crusher or rechipper. The material that has passed through the screen is moved to the air blast cleaner which consists of a flat chamber equipped with a curved screen and air blower. The dust and undersized chips are blown from the screen or dislodged by the tumbling action.

Chip Recovery

The oversized chips and slivers rejected by the chip screens are resized either in chip crushers or rechippers. After processing, the resized chips are mixed with chips being conveyed to the screening and cleaning processes. In this way, any oversized chips that may have been improperly crushed and any sawdust generated during crushing will be removed, and only chips of uniform size will be supplied to the digesters.

Pulping

The cleaned, sized chips resulting from the fundamental process of wood preparation are now ready for pulping, the second fundamental process in the paper making sequence. Pulping is the process wherein wood is converted into fibers which are adaptable for use in paper making. Currently, four different pulping processes are practiced: mechanical, sulfate (Kraft), sulfite, and semichemical. In chemical pulping, the intercellular polymers (lignin and carbohydrates) are removed by digestion with the use of chemicals, whereas in mechanical pulping, all the wood material is used but the separation occurs between fibers and through the fiber walls. The operations involved in each type of wood pulping are briefly outlined so that wastewater sources and characteristics can be better understood.

Mechanical (Groundwood) Pulp

The basic operation of mechanical pulping consists of cutting the debarked log into small blocks and then forcing them against a grindstone in the presence of water. In the grinding operation, the block is reduced to a fibrous condition. Water is used to cool the grinding stone, to clean, and to act as a lubricant for the surface of the grinding stone as well as being the pulp carrier. Carriers currently used in this operation may be grouped into three categories; pocket, magazine, and a combination pocket/magazine. The factors which affect the operation are the condition of the pulpstone surface, speed of the stone, operation pressure, grinding temperature, and the physical condition and species of the wood block being ground.

An alternative method of producing groundwood pulp utilizes steam in a pretreatment process, and the resultant pulp has a poor color but a higher strength than otherwise attained in mechanical pulping.

Recently, chemigroundwood pulping has been developed and is particularly applicable for use in conjunction with regular groundwood pulping where hardwood sources are available. The most distinctive feature of the chemigroundwood process is that the entire log is cooked. After the log has been soaked in a liquor consisting of sodium sulfite and sodium bicarbonate, the log is ground. Savings are effected since chipping and associated equipment requirements are eliminated. Yields from chemigroundwood pulping are as high as 85-90 percent, and are only slightly less than yields attainable by groundwood pulping. Advantages of this process over mechanical pulping are faster drainage and greater strength while requiring less power and providing better utilization of woodlands.

During the past several years, mechanical pulping from chips (refining mechanical pulp) has increased due to many factors including the lower capital and operating costs and the availability of chips from saw mill waste and other wood by-products which can be used in this process. The equipment required to manufacture mechanical pulp from chips includes a disk refiner (either one of two stages), a "pump through" refiner, and a centrifugal cleaner.

Sulfate (Kraft) Pulping

Kraft pulping utilizes alkaline solutions to dissolve the lignin and other non-cellulose portions of the wood which cement the cellulose fibers together. Alkaline cooking agents used in this process are caustic soda and sodium sulfide, and the "active alkali" is the sum total of the weight of these two chemicals expressed as sodium oxide. Since the amount of active alkali present in the cooking liquor is determined by the type of pulp being produced, the amount present varies from mill to mill, with a typical range of 18 to 20 percent based on oven dry wood. The resultant pulp is brown in color, difficult to bleach, and resistant to mechanical pulping.

The Kraft process is a cyclic system wherein the chemicals are recovered for direct reuse, and the dissolved organic residue is used for steam and power generation. The digestion process involves filling the digester with chips and cooking liquor, introducing steam into the digester, and increasing the pressure until the final cooking temperature is reached. During the initial cooking stage several reactions take place: air is removed from the digester by displacement with steam; liquor penetrates into the chips; volatile constituents of the wood (i.e., turpentine) begin to distill off: and the more soluble solid constituents of the wood being to dissolve. At a pressure of about 50 or 60 psi, mercaptans and sulfides begin to form and the rate of delignification increases rapidly. As the pressure and temperature continue to increase, the evolution of non-condensable gases begins to taper off. It is important that all non-condensable gases and air be expelled from the digester during the cooking period, otherwise the temperature would be less than that of the steam at that pressure and would result in a raw cook. The maximum cooking pressure is reached in about one to five hours at 100 to 135 psig with a cooking temperature of 340°F to 350°F. After digestion, the pulp mass is blown directly into the blow tank where the contents are diluted by spent cooking liquor.

The Kraft spent cooking liquor, "black liquor", contains the spent cooking chemicals as well as lignin and other solids extracted from the wood. It can be reused to constitute about 40 to 60 percent of the total liquor in the digester. The reuse of black liquor increases the solids content of the final spent liquor but decreases the quantity discharged to the recovery system.

The digestion techniques can be classified into three categories - batch cooking, injection method, and continuous digestion. Batch cooking is usually accomplished in a large pressure cooking vessel, a stationary digester, with chips and liquor introduced into an opening at the top while the steam enters from the bottom. The injection method alternative requires the injection of the fresh reagent into the forced circulation line in the digester, and consequently does not require a high initial chemical-to-wood ratio since the chemicals can be added as they are needed. Although less chemicals are required, the disadvantages of longer cooking time and higher power consumption have limited this application. The continuous digestion method, as the name implies, produces a steady flow of pulp, and is accomplished by preheating the chips in a steaming vessel and then feeding the chips to the digester where they are impregnated by the cooking liquor which has been heated and recirculated through heat exchangers. Although the advantages of this method include heat conservation, reduced costs for accessory equipment, elimination of peak steam demands, reduction of corrosion problems, and the production of a uniform pulp. The disadvantages of low surge capacity, lack of flexibility, and excess wastage during start-up have limited the acceptance of this method in the past. However, the majority of the large new mills being built are incorporating continuous digestion, and the tendency is toward even more frequent adoption with the development of the sulfate pulping process.

Recent pilot-plant installations have included prehydrolysis sulfate digestion; the chips are treated in the first stage segment of the digester, then subjected to countercurrent cooking in the second stage. Prehydrolysis is kept to a minimum while by-product (turpentine) recovery is enhanced. Development of this method is directed at the reduction of the hemicellulose degradation, which would result in increased yields from the Kraft process.

Sulfite Pulping

The sulfite pulping process is based on the digestion of wood chips in an aqueous solution containing metallic bisulfite and an excess of sulfur dioxide. The primary reaction of the sulfite pulping process involves the solubilization and sulfonation of lignin and the hydrolytic splitting of lignin-cellulose complex.

The digester used in sulfite pulping is a large cylindrical vessel with a conical bottom. After the digester has been filled with chips, a chip packer evenly distributes the chips over the cross-section of the interior in order to achieve uniform settling. Next, the digester is closed with a metal cover and the cooking acid is pumped into the unit.

Two types of systems are possible; hot acid and cold acid. In the former, the liquor is added from a spherical storage vessel (an accumulator) at a temperature of about 80°C. and 60 psig, while in the cold acid system, the temperature is only about 30°C. and the liquor is added at atmospheric pressure.

The main advantage of the hot acid system over the cold acid system is that it saves about two hours pulping time and about 2,000 pounds of steam per ton of pulp. This is because of its ability to contain higher concentrations of sulfur dioxide. Also, the higher temperature increases the rate of penetration while decreasing the cooking time. Most of the mills are now using the hot acid system with calcium-base sulfite pulping; yields are about 50 percent.

Either direct or indirect heating operations can be used. In the direct heating operation, steam is introduced into the digester directly and uniform heat can be maintained with the aid of external circulation of the liquor. If external circulation is not provided, careful application of steam is essential in order to promote circulation. Since steam condensation dilutes the liquor in the digester, higher concentrations of chemical are needed in the digester liquor. It is also necessary to withdraw liquor from the digester at a side relief to maintain the proper liquid level and to permit gas relief from the digester without plugging the top relief strainers (which prevent chips from being carried out of the digester).

Indirect heating is accomplished by forced circulation of the liquor within the digester with heat being applied indirectly with the use of a heat exchanger. This method has the advantage that uniform temperature and chemical concentrations are maintained throughout the volume of chips in the digester resulting in a more uniform pulp product. Another advantage of the indirect heating procedure is that the steam condensed in the heat exchangers can be returned to the boilers for reuse.

After cooking, the digester is blown with the contents forced to a blow tank. In the blow tank, the chips and liquor are forced against a stainless steel target plate, resulting in the chip structure breaking into individual pulp fibers. The sulfite liquor drains through the bottom of the blow tower and may be discharged to the sewer or collected for recovery.

Because of the low cost of limestone, no attempts were made in the past to recover this chemical from the spent liquor, which contains non-volatile solids in concentrations of about 8 to 12 percent with dissolved organic concentrations of about 10 to 12 percent. The remaining material present will be residual calcium bisulfite, other inorganic salts (such as calcium sulfate), and a small amount of organic substances. Alternatives to the calcium-base in sulfite pulping have been developed which include ammonium, magnesium, and sodium bases.

In the ammonium-base bisulfite liquor, cooking time can be decreased with a resulting increase in production. The ammonium ion tends to diffuse more readily and improves liquor penetration into the chips, resulting in increased yield and a more uniform pulp quality. Another advantage is that a wider range of wood species can be utilized because of the greater solubility of resin and other acids in ammonium salts. In the preparation of the cooking liquor, the ammonium hydroxide or liquid ammonia is used, while the procedures for carrying out the pulping operations are similar to those used in the calcium-based system, except that the greater solubility of ammonium salts permits a somewhat lower combined sulfur dioxide concentration in the liquor.

The magnesium-base sulfite pulping process was first developed in 1914, but now is receiving close attention since the recovery of heat and chemicals from the spent liquor is feasible. An 80 to 90 percent recovery of the magnesium base can be expected with the proper operation of the recovery system; however, to convert existing facilities from calcium to magnesium-base pulping, some modification of the processing operation would be required.

The sodium-base sulfite pulping process has recently been developed by the industry, and the operating advantages are similar to those discussed for ammonium and magnesium. In addition, there is increased versatility since pH levels in the digester can readily be adjusted during operation. The recovery of the spent liquor has been successfully developed and practiced by the industry, and the relatively higher costs involved in the sodium-base sulfite pulping process may be justified by improved quality, capacity, ability to handle more resistant woods, as well as the reduction of the wasteloads generated.

Of approximately 60 sulfite pulp mills in this country, all but a few are more than 20 years old. Most of the mills are using either the calcium-base or the ammonium-base process with no practical recovery methods for chemicals and liquor. However, some mills have instigated the practice of evaporation and combustion of the spent liquor for heat recovery and waste reduction. Several newer mills have been built using magnesium-base and sodium-base sulfite pulping processes with chemical and liquor recovery.

As stream pollution controls become more stringent, the sulfite mills are being restricted in their practice of discharging the untreated waste liquor into the streams. Consequently, many mills are planning to change the sulfite process from calcium-base to magnesium, ammonium, or sodium bases where economical recovery of the spent liquor is feasible.

The most recent development in sulfite pulping is the adoption of multistage processing, where each stage would differ in degree of acidity and alkalinity. The first stage is designed for optimum penetration of the cooking liquor into the wood and also to initiate the wood softening process; in the second stage, the dissolution and removal of reacted lignin is maximized. To date, this technique is still experimental, and no large scale industrial application has been developed.

Semichemical Pulp

The semichemical process produces pulp from chips using a mild chemical treatment to soften the chips thereby allowing mechanical separation of the fiber. With a pulp yield of about 80 percent, the process is much more efficient than chemical pulping where the yield will range from 43 to 50 percent. However, the strength and flexibility of the semichemical pulp is low when compared with the pulp produced in the chemical process. Currently, there are two semichemical pulping processes which have been adopted by the industry, neutral sulfite and the Kraft process (KSC).

In the neutral sulfite semichemical (NSSC) pulping, the liquor chemicals break the fiber bond in a process that involves lignin sulfonation and hemicellulose hydrolysis. The sodium sulfite is used basically as the main cooking agent, while sodium carbonate is added as a buffer to maintain a slightly alkaline pH during digestion. Smaller mills prepare the cooking liquor from sodium sulfite and soda ash, but the large mills generally prepare sulfite soda ash by burning sulfur and absorbing the gases in a packed tower through which a soda ash solution is circulated. The NSSC digestion procedures can be classified into two types, batch and continuous.

After the digester is filled with chips and cooking liquor for the batch process system the unit is heated to 120°C for one hour under excess steam conditions. Once the pulp is softened and partially digested, the stock is then discharged to either the blow tank or to blow pits filled with leach casters. The partially disintegrated stock, in a moist or slush form, is then pumped to deliquoring presses or directly to the fiberization machine. The disk attrition is widely used to refine or disintegrate this stock, and a number of different types are currently in operation. The end result sought is a moisture content in the fibrous material of about 50 to 60 percent, which in turn leads to higher pulp strength and lower fiberizing energy consumption.

Recently, the use of the continuous digester for NSSC semichemical pulping has been developed and practiced. Different types of digester are available commercially; horizontal-tube, downflow vertical, upflow vertical, inclined-tube, etc.

The KSC pulp, which is generally bleached, is increasing in production and has the advantage of using hardwoods, but the yield is about 65 to 70 percent, which is lower than that of NSSC pulp. The KSC liquor is a weak white liquor obtained from an associated Kraft mill liquor preparation system. Normally, the active alkali application is about 5 to 8 percent of wood as sodium oxide with a cooking time of less than 30 minutes for temperatures of 170°C to 180°C. The mechanical treatment for the KSC digested chips is the same as described for the NSSC process, while the recovery system for the KSC spent liquor is combined with the Kraft recovery system in an associated Kraft pulp mill. The future for KSC applications is promising because of the increasing number of Kraft mills being established.

Blow Tank

The digester contents, after they have cooled, are blown to a blow tank by the pressure remaining in the digester. The blow tank is used to separate the blow vapors from stock and liquor, and this operation is essentially associated with all types of pulping. The blow tank operation is not generally considered a fundamental process for the pulp and paper industry, but is discussed separately to achieve clarity.

After the cooked chips are blown into the blow tank or blow tower, the steam and hot gases escape from the cyclone separator vent on the top of the tank and then are sent to a heat exchanger where the heat and condensate are recovered. The stock drops to the bottom cone, where it is stirred by an agitator assembly rotating at about 20 rpm. After the stock is diluted to about 3.5 percent by introducing spent liquor, this mixture leaves the blow tank from an opening near the bottom, passes through a separator where scrap metal, etc. are removed, and is pumped to another screen or directly to washers.

Deinking

Deinking is the process of treating printed wastepapers for the removal of the printing ink and the recovery of the pulp in a condition suitable for reuse. In the future, this process may become one of the major sources of pulp as raw material sources diminish. The deinking process includes pulp separation, washing, screening, etc., because these operations are normally kept separate from other mill processes.

Most wastepapers are not deinked prior to being processed to manufacture roofing paper and boxboard, as only about 5 percent of total wastepaper used is treated to remove printing and writing ink. Available wastepapers suitable for deinking are printed books, magazines, and similar papers, where the principal fiber component is bleached chemical pulp, while the foreign materials include ink and pigments. Sorting wastepapers before deinking is essential for successful operation.

Deinking consists of fiberizing the printed wastepaper by mechanical action in conjunction with water, heat, and chemicals (usually alkalies). The ink is removed from the printed paper by saponifying, dissolving, emulsifying the ink vehicle, and thus releasing the ink pigment which can be removed from the pulp suspension by dilution, agitation and washing or flotation.

The chemicals used, the procedure followed, and the equipment employed in the deinking process may vary considerably. The process sequence depends on the composition of the grades of wastepaper used, the character of the printing inks, and the final usage of the recovered pulp. Broad generalities are not applicable to the deinking of wastepapers; special cases must be considered from one mill to another.

The chemicals used in the deinking of printed papers usually comprise alkalies such as caustic soda, soda ash, or sodium phosphates, together with surface-active chemicals (anionic, cationic, nonionic, and mixed anionic-cationic) employed as wetting agents and detergents.

In the older technology, little wastewater was reused because either an ample water supply was available or pollution control measurements were not enforced. Present day technology is toward the use of washers in series with proper water reuse. A very definite saving in water, heat, and chemicals may result from reuse of the first wash water from the washing cycle. This saving may be as high as 50 percent on steam and alkali used in high consistency cooking, and as high as 85 percent in the low consistency cooking process.

Since wastewaters generated in the deinking of printed papers contain ink, clay filler, and other contaminants, recovery of chemicals from these wastewaters has not been found practical.

Other Sources of Pulp

Rag pulp is a small but important source of fiber for the manufacturing of fine quality papers. Process operations include thrashing, color-segregation, sorting, cooking, washing, bleaching, and rewashing for pulp production. The cooking chemicals include caustic lime, caustic soda or a mixture of caustic lime and soda ash.

Another source of pulp that has been developed within the past two decades is bagasse. Almost all chemical pulping processes are applicable to the pulping of bagasse, but the Kraft or modified soda process with extra sulfur usually gives best overall results. Bagasse pulps are used in practically all grades of paper, including bags, wrapping, printing, writing, toilet tissue, facial tissue, toweling, glassine, and even newsprint.

Pulp Washing

Pulp washing is the process designed to remove the liquor and other foreign materials from the pulp. There are two types of equipment which have been used for the washing operation; the diffuser and the rotary drum vacuum filters.

Diffuser

The diffuser is essentially a large tank with a false bottom constructed for the drainage of the liquor and the collection of the washed pulp. After the cooking is completed, the stock and spent liquor from digesters are blown directly into the diffuser through the opening of a cyclone receiver mounted on top of the diffuser. The steam vapors rise to a cyclone-type catchall. From the catchall, the steam goes to heat exchangers, where the heat is recovered. At the same time, when the digester has emptied into the diffuser tank, liquor drains through the false bottom screen plate and is pumped to either spent liquor storage or to the sewer. Then, fresh water is admitted and the washing operation is started. Usually, several washings are required before the pulp is clean. After the pulp has been sufficiently washed, the gate located in the bottom of the diffuser is opened and the stock is sluiced out. Usually, several diffusers are often operated cooperatively for pulp washing. When this is the case, the cleaner discharge from the washing operation of one diffuser is reused for the first washing, but are being replaced by the more efficient vacuum filters.

Vacuum Filter

The vacuum filter consists of a large cylinder with woven-wire-covered drum rotating in a vat filled with diluted stock, with a shower located across the top of the drum. The drum is divided into a number of sections for the proper distribution of different operations involved in the pulp washing. Normally, the cyclic operations include the sheet forming, drainage, washing, and the removal of the cake. By the application of vacuum, the vat liquor is drawn through the screen on the surface of the drum and the pulp sheet is formed. Washing of the pulp sheet is accomplished by the spray of the wash water from the skimmer system. Then, the pulp sheet is scraped off by a doctor knife or compressed air.

The consistency of the feedstock is about 1.0 to 1.25 percent. After sheet forming and initial drainage on the cylinder mold, the consistency is increased to about 10 or 15 percent. Wash water temperatures of 130°F or 150°F are normally used with the maximum temperature determined by the allowable temperature of the liquor leaving the system. Generally, wash waters hotter than 170°C may cause foaming problems.

The early vacuum-washer systems were single-stage units, in which spent liquor was used to dilute stock drawn into the drum along with large amounts of wash water, and then discharged. Since the efficiency of this unit was low, washers in series or multi-stage countercurrent washing are used either of which reduces water requirements considerably. In the operation of the multi-stage vacuum filters, the stock scraped off the drum is repulped with the filtrate from the next succeeding stage and transported to the filter. The cleaned pulp is collected from the last stage of the system where fresh water is used for repulping and washing. The filtrate from the first stage is sent to the evaporator for liquor recovery, to spent liquor storage, or to the sewer. It has been customary to remove the knots from the pulp after washing on brownstock washers, but preknotting has the advantage of forming a uniform, dense, easily washable cake. Knotting prior to washing is used especially for the washers equipped with a press roll that is used to increase the density of the pulp sheet. Nowadays, most mills are using multistage countercurrent vacuum filters for pulp washing. Except for some sulfate pulp mills, the completely closed system for the spent liquors discharged from washers is still only a goal because of the problems reflected from the liquor recovery system. One significant disadvantage present in the vacuum filter operation is that the contact time between the stock and wash water is relatively short and does not permit complete removal of spent chemicals from the pulp by leaching and diffusion.

Liquor Recovery

Cooking liquor recovery was developed in order to reduce the cost for cooking chemicals and reduce the wastewater loads being discharged to streams. The recovery technique is different with each type of pulping method.

Kraft Liquor

The Kraft liquor recovery system is essentially a part of the pulping process. By means of evaporation, burning, and causticizing, the chemicals used in the cooking liquor can be recovered for reuse, while the dissolved organic residues from wood resins can be used for heat and power generation.

The spent cooking liquor (known as black liquor), after separation from the pulp stock, is pumped to multi-effect evaporators where it is concentrated from 16 to 18 percent solids to about 50 percent total solids. When increased liquor recoveries are practiced, the feed solids concentration will be about 13 percent. The concentrated mixture is then sent through a cascade, or disk evaporator, where combustion gases from the recovery furnace further concentrate the liquor to approximately 60 percent solids. The concentrated liquor is next sprayed into a furnace where heat is generated by the combustion of organic materials, and the inorganic solids (Na_2S and Na_2CO_3) melt at the high temperature. The melted solids are discharged from the base of the furnace into the dissolving tank where the smelt is dissolved in water to form a solution known as green liquor. The green liquor contains sodium sulfide, sodium carbonate and some carbon and iron. After processing through clarification, the green liquor is causticized by the addition of lime and the heat in the causticizer, and sodium carbonate and lime are converted to sodium hydroxide and calcium carbonate. After precipitation, the white liquor is recovered in the clarifier overflow. Calcium carbonate in the underflow is converted into lime by burning in either a rotary lime kiln or in fluidized bed incinerators.

In spite of the most careful control, some soda is lost in the washing operation, and these losses are made up by the addition of salt cake to the liquor as it enters the furnace. The salt cake is then reduced to sodium sulfide in the combustion process.

Sulfite Liquor

Sulfite liquor recovery techniques are more complex and difficult than those employed in the sulfate system. In the past, the spent liquor from sulfite pulping was discharged directly into the sewer. Because of the cost of chemicals and pollution abatement programs, complete or partial recovery systems are becoming more common. With the use of bases other than calcium, the closed system for spent liquor recovery is expected in future applications.

In the spent liquor, the quantity of organic solids equals about one-half of the original weight of wood. However, other chemicals are combined with lignin. The feasibility of liquor recovery is highly dependent on the base involved in the sulfite liquor; e.g., the calcium-base sulfite liquor can only be evaporated to approximately 60 percent solids and then burned for the production of power. When the evaporated sulfite spent liquor is burned, the calcium combines with the sulfur to form calcium sulfate. It is generally conceded that liquor recovery from calcium-base pulping is not economically feasible, especially considering that burning for heat production involves the problem of scaling on the wall of evaporators and furnaces.

For the magnesium-base sulfite liquor, the spent liquor is evaporated and burned. During burning, the organic residues are completely disposed for the generation of heat, and the magnesium is converted into magnesium oxide. The sulfur passes off in the combustion gases as sulfur dioxide. By making a slurry of magnesium oxide ash, the slurry may be used in the absorption tower to absorb the sulfur dioxide in the cooled combustion gases. Thus, the cyclic process for the magnesium bisulfite pulping is possible with the makeup of MgO and SO_2.

In the sodium-base sulfite process it is possible to recover the inorganic chemicals with a fairly complex process. After the spent liquor is evaporated and burned, the smelt of sodium carbonate and sodium sulfite is collected from the bottom of the furnace. By carbonation or crystallization, the relatively pure sodium carbonate is recovered, while hydrogen sulfide is evolved and is burned to yield sulfur dioxide. By using a sulfiting tower, the sulfur dioxide is absorbed by sodium carbonate to form sodium bisulfite, which is suitable for reuse.

Spent chemicals from the ammonium-base sulfite pulp process can only be partially recovered. By simple evaporation and combustion, only sulfur dioxide can be economically recovered together with the generation of steam and power. But with the complicated processes of fortificating, heating and pyrolysis, the gases of SO_2 and NH_3 are produced from the spent liquor. After passing the gases through a scrubbing tower, it is possible to recover 70 to 88 percent of the SO_2 and 99 percent of the NH_3. Unfortunately, this recovery method does not appear to be economically promising.

Semichemical Liquor

Liquor recovery in the neutral sulfite semichemical (NSSC) system is described here. The recovery of liquor in the Kraft semichemical system is the same as that of the regular Kraft process.

The recovery methods in use are now handled by integrated semichemical-Kraft "cross recovery", and the carbonation method. The "cross recovery" method is based on the sodium and sulfur values in the NSSC liquor that can be used as chemical makeup in place of salt cake. The NSSC spent liquor can be combined with Kraft liquor for evaporation and combustion, but the NSSC cooking liquor has to be made from fresh chemicals.

The carbonation method is a complicated process practiced in some independent NSSC pulp mills. Following conventional evaporation and burning procedures, a smelt of sodium sulfide and sodium carbonate is produced, while the flue gas is high in sulfur dioxide, and carbon dioxide. By passing the flue gas through the sulfiting tower, the sulfur dioxide is removed and only the carbon dioxide remains in the effluent gas, which in turn is used to carbonate the dissolved smelt to form hydrogen sulfide and sodium bicarbonate. The hydrogen sulfide can then be burned into sulfur dioxide in the furnace, and the sodium bicarbonate is converted to sodium sulfite in the sulfiting tower.

Pulp Screening and Cleaning

The objective of pulp screening and cleaning is to separate the coarse fiber from the fine fiber and to remove dirt and foreign matter; i.e., slivers, uncooked chips, grit, sand, etc. There are two separate screening operations involved in most pulping operations; coarse and fine screening, which do not generally follow each other in sequence. In most instances, coarse screening is followed by washing, thickening and dewatering, which in turn is followed by fine screening. Since fine particles of dirt, grit, and other unacceptable matter are not removed in either screening process, many mills add another cleaning operation, the centrifugal cleaner.

Coarse Screening

Coarse screening is used to remove oversized material, such as knots, large slivers, and unground pieces. Coarse screens usually have 1/4 to 1/2 inch circular perforations and may be a vibratory, mechanical, or rotating type. Vibrating screens consist essentially of a partially submerged perforated basket, the accepted pulp flowing through the perforations, while the rejects travel over the end of the screen to be recovered or carried away for disposal. Most mechanical screens consist of an inclined perforated plate from which the rejects are removed by a mechanical scraper. The rotating screen uses an inclined perforated cylinder in which there is a shower, which washes the pulp through the cylinder. The rejects travel downward and emerge from the lower end.

Coarse screens can be classified according to the application:

1. Sliver screens are used in the groundwood pulp process to remove the coarse material. The most common types of sliver screens used are bull screens, rotary screens, and rotary oscillating plates.

2. The knotter is a compact, simple machine with a rotating cylinder that is used to remove the partially cooked chips and knots from chemical pulp and slivers from groundwood pulp. In other mills, especially those using diffuser washing, the knotting operation was placed after the washing operation. Now, many mills employ the knotter screen before the vacuum filtration washing cycle to protect the filter.

Fine Screening

The purpose of fine screening is to separate the fibers into grades according to their dimensions. Normally, fine screening is performed after pulp washing and thickening in order to prolong the life of the screen. However, some mills have successfully combined coarse and fine screening into one operation. The three categories of fine screens currently used are inward-flow rotary, outward-flow, and flat screens. Openings in the screens vary from 0.025 to 0.075 inches; the size of the opening being governed by the quality of the paper being produced.

In the older technology, the flat screen was widely used; wherein the pulp suspension flows over flat metal plates perforated with slot with vibrating diaphragms below the plates inducing screening action. Acceptable fibers and small dirt particles pass through the slots while showers move the rejected material over the end of the screen box for subsequent rescreening or rejection. Application of flat screens is limited because of the low rate of pulp flow with a resultant large area requirement for the installation.

The outward-flow screen, widely used in present operations, consists of a cylindrical screen chamber with perforated plates through which the stock is thrown by the centrifugal action of the rotating impeller.

Inward-flow rotary screens have a vat for the unscreened pulp, within which a screen cylinder rotates. Acceptable pulp flows through the screen plates while an internal high pressure shower is used to backwash the partially submerged screen.

Cleaning

The centrifugal cleaner is the most frequently used device in pulp cleaning operations to remove grit and other small particles. Although several types of centrifugal cleaners have been developed, all rely on the magnified gravitational forces generated by introducing a dilute pulp suspension under relatively high pressure into a conical vessel. Materials that are heavy or unusually shaped are readily removed.

The placement of the cleaners in the pulping sequence varies according to the function of the cleaner. Many mills have the cleaning operation following coarse screening, while in other mills, the cleaners are placed either before or after fine screening operations.

Thickening and Dewatering

The thickening or dewatering process is used to concentrate the screened pulp and to increase its consistency. The water removed is usually returned to be reused in diluting fresh pulp for screening or is wasted to the sewer. The thickeners used for integrated pulp and paper mills are either deckers or vacuum filters. Thickening and dewatering operations can be applied in numerous areas and sequences since it may be used after pulp washing, after fine screening, before bleaching, or after bleaching.

1. The decker is also referred to as a gravity thickener, and the attainable pulp consistency is about 3 to 6 percent. The decker consists essentially of a vat for diluting pulp and a wire-cloth covered cylinder to allow the water to be removed from the pulp. The pulp level in the vat is maintained 3-6 inches above the top of the cylinder, while the water level inside the cylinder is kept as low as possible to increase the head for gravity flow. The cylinder

is cleaned periodically by a high pressure shower or steam jet to remove the dewatered pulp. The decker thickeners were used in the older technology but, because of their long processing time requirement and the low dewatering capability, they have largely been replaced by vacuum filters.

2. The vacuum filter used for thickening is essentially the same as that described previously for pulp washing. Vacuum filtration dewatering can obtain a consistency of about 15-25 percent. The advantages of the vacuum filter over the decker are the reduced floor space requirements, fiber loss, and maintenance costs. In many mills pulp washing is incorporated into the vacuum filter thickening operation. This is particularly true for the multistage, countercurrent systems.

Bleaching

The objective of the pulp bleaching process is the production of a brighter pulp, as measured by light reflectance. The main light-absorbing substances in wood pulp are derived from the lignin, resin, metal ions, and noncellulose carbohydrate components of the original wood. Therefore, to obtain a whiter pulp, these substances must either be removed or chemically changed to diminish their light-absorbing characteristics.

For groundwood pulp, the removal of the lignin and resin would result in a substantial reduction in pulp yield, which eliminates its main advantage (high yield) over chemical pulps. Similarly, for cold soda and chemigroundwood pulps, extremely high brightness (85 to 90 percent as measured on a G.E. reflectance meter) is not commercially feasible because of the high lignin content of the pulps. The brightness increment in these pulps is obtained solely through the removal of color bodies using oxidizing agents (peroxides) and reducing agents (hydrosulfites).

Bleaching of groundwood and high-yield semichemical pulps with peroxide or hydrosulphite was previously accomplished in one stage; however, the tendency is now toward two-stage peroxide-hydrosulfite bleaching to obtain a higher degree of brightness. Cold soda pulps are also being bleached in two-stage peroxide-hydrosulfite process.

For Kraft, sulfite, and neutral sulfite pulps, initial removal of lignin is achieved by cooking with alkalies, sulfides, or sulfites. The bleaching process includes further delignification of the pulps by chlorination, caustic treatment for the removal of alkaline-soluble chlorolignins, and one or more bleaching stages using sodium or calcium hypochlorite or chlorine dioxide as oxidizing agents. Washing is necessary after each stage in multistage bleaching processes.

Presently, the three-stage bleaching sequence - chlorination, caustic extraction, and hypochlorite bleaching - is used for sulfite and semichemical pulps, except when a very high degree of brightness is required. Since the initial brightness of sulfate pulp is below 45, while sulfite pulp averages about 60, it is much more difficult to bleach the sulfate pulp to the same final brightness attainable for the sulfite pulp. It is not uncommon for mills to use five-stage bleaching of sulfate pulp if the extra brightness is required.

Basically the same chemicals and bleaching sequences are necessary when bleaching deinked pulps. Where a very high degree of brightness is not required and the pulp has a low groundwood content, single-stage hypochlorite bleaching is the most frequently used process. As discussed in the deinking section, three stage bleaching is required when the groundwood content exceeds 40 percent.

The degree of brightness obtained is of course directly related to the degree of lignin removal obtained prior to oxidative bleaching. Alkaline extraction, after chlorination, is necessary for sulfate and NSSC pulps (often omitted with sulfite pulps). In recent years, chlorine dioxide has been used extensively for oxidative bleaching although specialized bleaching chemicals have been developed for nearly every type of pulp and end-product requirement.

It has been established that greater brightness can be achieved with less degradation if smaller amounts of bleaching agents are applied in successive stages with washing between stages. However, the use of a large number of stages has the disadvantages of higher capital costs, loss of fiber, and increased water usage. The present aim is to reduce the number of stages required to produce the specified pulp quality. With the development of chlorine dioxide as a bleaching agent, many modern bleach plants have only five stages to produce very white, strong pulps.

Since there is a variety of multistage bleaching sequences available for each type of pulp, the quantity of wastewater generated varies in accordance with the number of stages involved, the number of washing steps, and the amount of water reuse in the process. In older mills, there had been no water reuse employed in the washer, but technological advances have allowed for more efficient use of water in the multistage bleach plant.

Two types of water recirculation can be used in the bleach plant. Within the individual stage, the filtrate from the washer seal box can be reused to dilute and convey the stock going to that same washer. This represents an extremely large amount of filtrate; but since it is mainly an internal recycle, the water demand from outside the system is minimal. The other recycle method involves a transfer of excess filtrates from the final washer seal boxes to earlier stages in the bleach sequence, thus maintaining a counter-current flow of filtrate from the bleached end toward the unbleached end of the plant. The use of fresh water in the showers assures that the sheet going into each bleaching stage will be relatively free from dissolved organic matter, which would otherwise consume bleaching chemical. For maximum water conservation, only the overflow from the chlorination and the first caustic extraction stage are sewered.

It is important when reusing white water in a bleach plant to consider not only the quality of the water and the dissolved material content, but also the temperature and type of fiber content. For optimum utilization of chemicals or heat, it is preferable to keep the acid and alkaline filtrate streams separated and the high and low temperature waters should also be discharged to separate streams. Typical recycling systems are shown in Drawing No. B-3.

Stock Preparation

Stock preparation is defined as that part of the pulp and paper making process in which pulp is treated mechanically, and often chemically, using additives to make it ready for forming into a sheet on the paper machine. Stock preparation in a paper mill includes all intermediate operations between preparation of the pulp and fabrication of the paper, and would consist of: 1) preparation of the furnish including consistency regulation and proportioning, 2) beating and refining, 3) machine chest mixing, and 4) screening.

Furnish is the term used for the mixture of water, pulp and chemicals which ultimately goes to the paper machine for fabrication into paper. The furnish of a paper machine varies widely, depending on the grade of paper being made. For example, newsprint is generally a mixture of 15-20 parts of unbleached sulfite pulp and 80-85 parts of groundwood pulp with no chemical additives. Bond paper may be 100 percent sulfite or a combination of sulfite and rag; it usually contains 5-10 percent filler and a starch surface sizing application.

The integrated mill receives pulp in a slush form with a consistency of 3 to 15 percent, though there are instances where the pulps are dried, stored, or transferred to be used later in the form of a roll, lap, or dry baled sheets. Slushing will be required to fiberize or disintegrate the dry sheets or laps of pulp in water to form a slush of separated fibers. Slushing can be accomplished in beaters or by machines known as pulpers.

Consistency regulators are used to regulate the amount and the consistency of the stock that goes to beaters, refiners, or to the paper machine. There are two types of consistency regulators: open and pipeline. Since both types work by dilution, the stock coming to them must have a higher consistency than that desired in order for the controller to function.

The various stocks which make up a multi-stock furnish are proportioned by many different methods. The most prevalent method has been the use of a multi-compartment stock regulating box provided with suitable inlet, outlet, and overflow ports and adjustable weirs which permit adjustment of the amount of each stock being added to the furnish. As with consistency regulators, the use of enclosed proportioning devices installed in stock lines is practiced. Open-head, box-type proportioners are also used.

Fillers, or "loading", are included in the furnish to give paper increased opacity, brightness, bulk, weight, flexibility, softness, smoothness, or printability. The usual loading materials are very fine grained powders of clay, talc, diatomite, gypsum, calcium carbonate, calcium sulfate, titanium dioxide, barium sulfate, and zinc sulfide. These can be added in slurry form to the beater during stock preparation. Since only a portion of the filler leaving the paper machine headbox is retained in the sheet by interaction of filtration or co-flocculation, spillage from white water systems should be minimized to avoid filler wastage and objectionable mill effluent. The majority of the filler retained on the sheet is concentrated in the top (felt) side, resulting in "two-sided" sheets.

Sizing is the treatment which makes the paper or stock resistant to liquids, particularly water. All papers are sized except blotting and other absorbent papers where penetration is desired. Rosin, various hydrocarbon and natural waxes, starches, sodium silicate, glues, casein, synthetic resins, and rubber latex are among the materials used as sizing agents. Addition of the agent can be made by several alternative methods. When the agent is added directly as a beater additive, it is commonly known as "stock" or "engine" sizing. The sizing agent can be added in the form of soap made from the saponification of rosin with alkali or as a wax emulsion. The size is precipitated using paper makers' alum, $AL_2(SO_4)_3.18H_2O$. As a result of this treatment, a gelatinous film forms on the fiber which loses water of hydration and produces a hardened surface. Sodium aluminate may also be used to precipitate the rosin size.

An alternative method of adding the agent is to run the partially dewatered paper through a size solution or over a roll wetted with a sizing solution. Sheets processed by these methods are known as "tub-sized" or "surface sized".

Wet strength resins have become important additives in the manufacture of papers that have greater than 10 percent wet over dry tensile strength when saturated with water. Aminoaldehyde resins can be added to the stock at the beater or at the wet end of the paper machine.

Coloring is often applied to the paper to improve its appearance. Dyes used are either added to the stock in the beater or at other points ahead of the paper machine. All types of dyes (acid, basic, direct, sulfur) and all types of pigments (both natural and synthetic) are used as coloring agents. The acid dyes (negatively charged ions) have no affinity for the cellulose fibers (also negatively charged) and must, therefore, be fixed to them by means of mordants. If the paper is colored in the beater, the alum that is added to precipitate the size will also act as a mordant for the dye.

Pulp stock is prepared for formation into paper by two general processes, beating and refining. There is no sharp distinction between these two operations. Mills use either one or a combination of the two. However, the use of beater operation is decreasing with the increased use of continuous refining, which produces better results.

Beating is the mixing together of the various materials in a water suspension, and by means of mechanical action imparting properties to the materials that determine the character of the finished product. Beating the fibers makes the paper stronger, more uniform, denser, more opaque, and less porous. Beaters (known also as Hollanders) are extensively used in rag, rope, and fine paper mills. Beating can be either intermittent or a batch process.

Refining is a mechanical treatment that can be used alone or after beating. It contributes to fiber separation, fiber brushing, and fiber shortening, where the objective is to improve formation and to better adapt the fibers for forming on the paper machine. Because of the possibility of continuous operation, refiners are now used almost exclusively for the large tonnage papers, such as wrapping, bag, and newsprint; they are also replacing beaters in the production of the more highly processed grades of paper. Two types of refiners are available: the Jordan refiner is typical of the conical (plug-and-shell) types; and the Bauer refiner is typical of the disk type.

After the stock is refined, it is usually retained in a machine chest (also called a stock chest) for an hour or more before it is sent to the paper machine. An agitator paddle or propeller in the chest provides thorough mixing of the stock. The consistency of the stock in the chest varies from 2-1/2 to 3 percent.

Paper Machine Operation

Converting the fiber suspension into the paper sheet involves three steps: 1) the random arrangement of the fibers into a wet web (paper machine wet end); 2) the removal of free water from the wet web by pressing; and 3) the progressive removal of additional water by heat (paper machine dry end). Two types of paper machines are used; the Fourdrinier and the cylinder machines.

The Fourdrinier machine has been successfully adapted to make a very wide range of papers and lightweight boards. Cylinder machines are employed for the manufacture of heavy paper, cardboard, or non-uniform paper. Because of the compact nature of the cylinder vat, multiple units have been combined in machines designed to manufacture multi-ply papers and boards.

In the Fourdrinier machine, the stock containing approximately one half percent fiber is sent through screens to the headbox and then flows from there through a sluice onto a moving, endless wire screen. Almost all the water and approximately one half of the fibers go on through the Fourdrinier wire, either to be caught by the wire tray or to fall into the wire pit. Since the wire has to be kept clean, pressure sprays are used for this purpose, and the spray water is collected at the wire pit. Water from the wire tray, which is the "richest" white water, flows into the mixing well, where it is mixed with the incoming stock and then pumped back into the headbox system by the fan pump. Some of the water that falls into the wire pit is used to maintain the water level in the mixing well, and the remainder overflows to be returned to the saveall system where fibers are reclaimed. In the older technology, the excess white water was sewered and not reclaimed.

In the newer technology, separate trays are used in the Fourdrinier machines to collect white water from forming rolls and to collect relatively clean water from the suction boxes. The rich white water from forming rolls is sent to a retention silo and recycled to mix with the incoming stock. Water from the suction box is collected in a tank and used for diluting the stock or as a spray on the wires. The balance of the white water collected at the wire pit is pumped to a saveall tank and then to the saveall system.

Savealls are essential for the reuse of water and for the recovery of huge quantities of fiber, additives, pigments, and other paper making chemicals which might otherwise increase the pollution loadings to the receiving streams. In a properly designed system, the saveall should recover at least 95 percent of the fibers and fillers. Several types of savealls are now in use: sedimentation, revolving cylinder (screening), vacuum filter, and flotation. The disk filter is favored because of its relatively high efficiency and minimal space requirements.

After the suction boxes, the sheet is of about 15 to 20 percent consistency, and the wire and sheet move to the first felt blanket which carries the sheet through a series of press rolls where more water is removed and the paper is given a watermark, if so desired. The paper then passes through steel smoothing rolls and is picked up by the second felt which carries it through a series of dry rolls heated by steam. The paper enters the rolls with a moisture content of 60 to 70 percent and leaves them 90 to 94 percent dry. It is next passed through the calender stack, which is a series of smooth, heavy steel rolls that impart the final surface to the paper. The paper produced is wound on the reel.

In the cylinder machine, a vacuum is maintained below the stock level in the cylinder in which the wire cloth is rotating, and the sheet forms on the wire by suction; a process similar to the formation of cake on a vacuum filter. The cylinder machine has from four to seven parallel vats into each of which similar or dissimilar dilute paper stocks are charged. This enables several layers to be united together into one heavy sheet. As a wire-covered rotating cylinder dips into each vat, the paper stock is deposited on the turning screen as the water inside the cylinder is removed. As the cylinder revolves farther, the paper stock reaches the top where the wet layer comes into contact with a moving felt. The traveling felts, carrying the wet sheet, passes under a couch roll to press out some of the water, and then into contact with the top of the next cylinder where another layer of wet paper is picked up. Thus, a composite wet sheet is built up and passed through press rolls to the drying and smoothing rolls.

The operating speeds of the Fourdrinier machines vary from 200 ft/minute for the finer grades of paper to 2,500 ft/minute for newsprint. Speeds for the cylinder machines do not often exceed 800 ft/minute.

Tab sizing is carried out on the dried paper or on surfaces which may or may not have been previously sized in the beating operation. The principal substances used are animal glue and modified starches since the treatment requires that the material have adhesive properties. The operation is carried out either on the paper making machine or in a separate sizing press that employs air drying. The paper runs through a bath of the size material, through squeezing rolls to remove the excess material, and then over drying rolls.

A limited amount of paper is colored by running the sheet through a dye solution (dip dying) or by applying a dye solution at the calenders (calender-straining). However, surface coloring uses less dye and requires the production of only one type of paper, which later may be colored any shade desired.

In the past, coaters were usually operated independently of the paper machine because the coater ran at a much slower speed. Today, all the large tonnage grades of medium quality coated paper are coated on the paper machine. Where heavy coating weights are needed or where special formulations or other conditions exist which do not permit application on the paper machine without slowing it down, papers are coated off the machine.

"Wet broke" is that material which has been rejected before the paper reaches the dryer. Several types of wet broke are produced in the course of the paper making operation and are handled in various ways. Wet broke may be allowed to run into a couch pit where it mixes with white water and is then pumped to the saveall, or it may be carted or conveyed to the broke beater or pulper.

"Dry broke" is that material which is rejected at the dryers, calender reel or winder, or in the finishing room. The dry broke is usually transferred to the pulper or broke beater for reprocessing.

Finishing and Converting Operations

Finishing operations refer to those operations which are performed in the paper mill finishing room and which are needed to prepare the paper for shipment. The finishing operations include:

1) supercalendering to improve the surface finish; 2) secondary slitting and rewinding to produce rolls sized to the customer's specifications; and 3) cutting of the paper into sheets if the end product must be in sheet rather than roll form.

Converting operations cover the modifications of the raw paper from the mill rewinder which improve the grade of paper with special properties or the fabrication of the paper into a finished article. There are two distinct types of converting. The first is referred to as wet converting, wherein the paper is handled in the roll form; modified by such operations as coating, impregnating, and laminating. The second type is known as dry converting, wherein a finished product is made from the paper; i.e., bags, boxes, house-household-size rolls, etc.

The basic procedures involved in finishing and converting are related to the grade of the end paper products. For example, newsprint is simply slit and rewound into rolls of the size required for the newspaper presses. Machine-coated book papers are supercalendered, and then slit, rewound or sheeted. The better grade printing paper receives a pigment coating in a separate operation (not on the paper machine), and are supercalendered, sheeted or slit, and rewound. Paper of writing grade is commonly sheeted, while the highest quality is often given a tub-sizing treatment. Packaging and wrapping papers are subjected to various protective and waterproofing coatings, laminating, and pigment coatings.

Most of these finishing and converting operations are performed under dry conditions and produce little liquid wastes except in the case of coating operations.

Mineral or pigment coating is important for improving the printability of paper. The basic mineral pigment coating used consists of a water suspension of a white pigment; usually clay with soluble binders of casein, starch, vegetable proteins, or synthetic resins. Most coatings also contain titanium dioxide which increases whiteness and opacity. Other pigments used include calcium carbonate, calcium aluminum silicate, satin white, and blanc fixe. Dyes are added for production of colored paper coatings. The preparation of coating mixtures is a highly refined art. The final mixture comprises dozens of ingredients including such materials as dispersing agents, preservatives, viscosity modifiers, antifoaming agents, leveling agents, softeners, and plasticizers.

Functional coatings to improve properties and range of paper usage are the second major coating field. Paraffin wax, bituminous asphalt, various lacquers and varnishes, both natural and synthetic, are used as protective coatings which also add gloss and improved appearance. Animal glues and rubber-base pressure-sensitive adhesives are applied to paper to be used as gummed tapes and adhesive tapes used for packaging. Greaseproof lacquer coatings and a wide variety of synthetic resins are used in a variety of protective coatings.

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